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EFFECT OF PHOTOCURRENT SHORTWAVE STIMULATION AND DETERMINATION OF DIFFUSION LENGTH FOR MINORITY CARRIERS IN Cu_2S

The most important parameter that defines efficiency in carrier collection and, respectively, efficiency of photoconverter, is diffusion length of minority carriers in material where basic light absorption takes place. For non-ideal heterojunction CdS-Cu_2S, the value of diffusion length for electrons L_n in Cu_2S is the most essential. In the given work non-destructive method diffusion lengths definition in this material is proposed.

The direct methods to determine diffusion length of current minority carriers exist, for example, the scanning of p-n junction face by electronic, light or mechanic probe. But for semiconductor photocells the most useful is to determine diffusion length by methods based on measurements of current or EMF, generated by photocells at different illumination. Such measurements do not require the special treatment of sample applying for the direct procedures. One of the most extent methods to determine diffusion length by steady-state photoelectric characteristics is the procedure based on analysis of photoresponse spectral dependence. But application of such methods (developed for photocells with homojunctions) for non-ideal heterostructures often does not lead to reliable results. This is connected with the fact that the shape for spectral dependence of short-circuit current $I_{sc}(\lambda)$ in non-ideal heterojunction is defined not only by parameters of basic layers (absorption spectrum $\alpha(\lambda)$, diffusion length L_n, thickness of absorbing layers h), but barrier parameter depending on photoexcitation conditions [1–2]. There are more complete formulas to define the dependence of collection coefficient Q (that defines short-circuit current without taking into account the phenomena connected with change in barrier parameters) on wavelength λ. Though, the approximation of element infinitely long base is often used in calculation of diffusion length. Such idealization for front-barrier photocells with rather thin, strongly absorbing basic layers (i. e. based on Cu_2S) can not be always justified.

In certain conditions formulas obtained for homojunction photoconverters may be applied for heterojunctions, moreover, in this case the calculations become even simpler. Thus, for example, under illumination of heterojunction on the base of CdS-Cu_2S from the side of wide-gap CdS, the latter at wavelength of exciting light $\lambda > 600$ nm plays the role of window, which absorption can be neglected. Short-wave spectrum region with $\lambda < 600$ nm is practically in full defined by light absorption in front layer (CdS) and therefore is not observed by us. Besides, all these barriers of CdS-Cu_2S heterojunction concentrates in wade-gap semiconductor, and in basic layer the fields are practically absent. This leads to essential simplification in expression for collection coefficient, which takes the form:

$$Q = \frac{\alpha L_n}{1-\alpha^2 L_n^2}$$

$$\frac{(1-\alpha L_n\sigma_2)sh\left(\frac{h}{L_n}\right)+(\sigma_2-\alpha L_n)sh\left(\frac{h}{L_n}\right)+(\alpha L_n-\sigma_2)e^{-\alpha h}}{\sigma_2 sh\left(\frac{h}{L_n}\right)+sh\left(\frac{h}{L_n}\right)}, \quad (1)$$

where $\sigma_2 = S_n L_n / D_n$. Here S_n — velocity of electron recombination on external surface of basic layer, L_n — diffusion length of minority carriers in Cu_2S, D_n — diffusion coefficient for electrons in Cu_2S.

At measurement of spectral dependence, photocell was illuminated from the side of wide-gap CdS, so at thickness of cooper sulphide being greater than diffusion length of holes in this material (the requirement for effective operation of photoconverter), the boundary condition on external side of Cu_2S film do not practically influence on the shape of photocurrent spectral dependence. In such conditions under calculations, surface recombination on external surface of basic layer can be neglected. Therefore, supposing $S_n = 0$ and, respectively, $\sigma_2 = 0$, expression (1) can be rewritten as follows:

$$Q = \frac{\alpha L_n}{1-\alpha^2 L_n^2}\,\frac{sh\left(\frac{h}{L_n}\right)-\alpha L_n sh\left(\frac{h}{L_n}\right)+\alpha L_n e^{-\alpha h}}{sh\left(\frac{h}{L_n}\right)}. \quad (2)$$

The numerical simulation of photoresponse spectral characteristics applying formula (2), for each wavelength ($600\ \text{nm} < \lambda < 1025\ \text{nm}$) it is necessary to set a value of absorption coefficient $\alpha(\lambda)$ in CdS-Cu_2S. The calculations of spectral

characteristics made on the base of two magnitudes for h (1 μm, 0.2 μm) at different values of L_n. (Figure 1) show that at values of Cu_2S film thickness being characteristic for thin-film elements CdS-Cu_2S the obtained spectral characteristics essentially depend on value h, so the approximation for infinitely long base are applied incorrectly at definition of L_n.

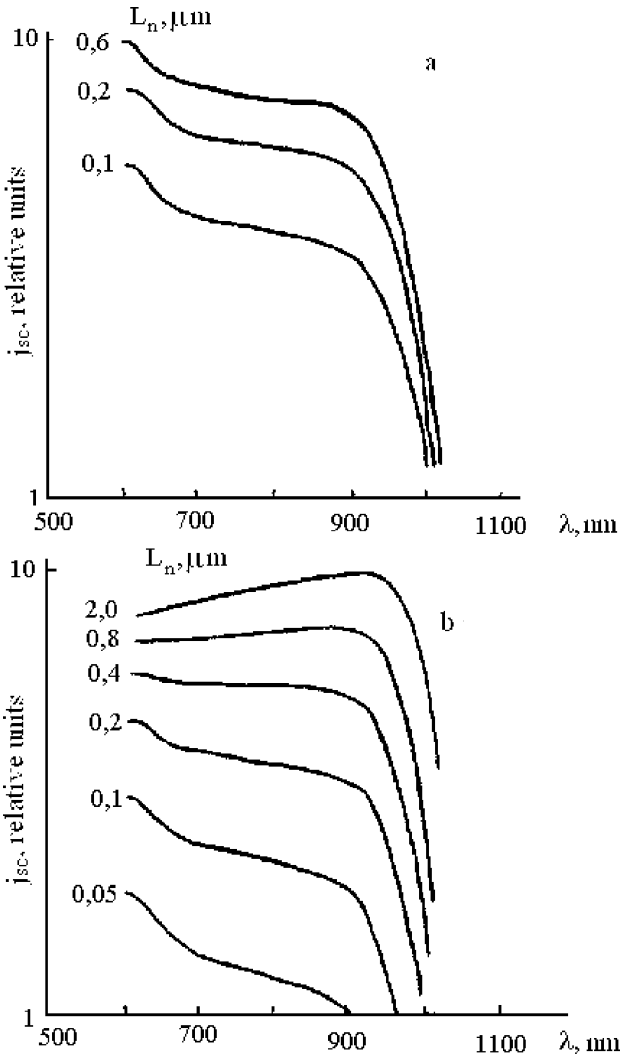

Fig. 1. Curves for spectral distribution of short-circuit current in CdS-Cu_2S heterophotocels, calculated for different values of L_n in Cu_2S at Cu_2S layer thickness — 0.2 μm (a) и 1.0 μm (b)

Spectral dependence for short-circuit current of photocell based on CdS-Cu_2S heterojunction with good photoelectric properties is shown in Figure 2 by curve 1. Thickness of Cu_2S layer numbered 0.6 μm. From Figure 2 it is well seen that simulation 5 (corresponded to $L_n = 0.05$ μm) being the nearest to research curve 1, does not though give good agreement. Moreover, such low value of diffusion does not agree with high (~7%) EMF for the given photocell.

Such contradictions, as it was mentioned above, could be caused by influence of exciting light on barrier parameters and, hence, on I_{sc} values. To determine diffusion length of electron in cooper sulphide by $I_{sc}(\lambda)$ curves one should provide the steady-state conditions for their collection independently on wavelength of photoexcitation. Such conditions should be provided by additional illumination from the range of absorption by CdS local centres (550—700 nm). But illumination within the range of intrinsic absorption is preferable, because this light is absorbed effectively and leads to generation of greater number of non-equilibrium holes that captured by local centres in space-charge region. In this case, electric intensity in space-charge region increases to the extent that monochromatic light applied to measure curve for spectral sensitivity is unable to change barrier parameters. Intensity of short-wave illumination was chose and its further increase does not lead to changes in shape of spectral dependence. Curve 2 (Figure 2) measured in such conditions indicates the considerable contribution of cooper sulphide to photocurrent generation and differs sharply on curve 1. Simulation curve approximates well experimental dependence at $L_n = 0.35$ μm.

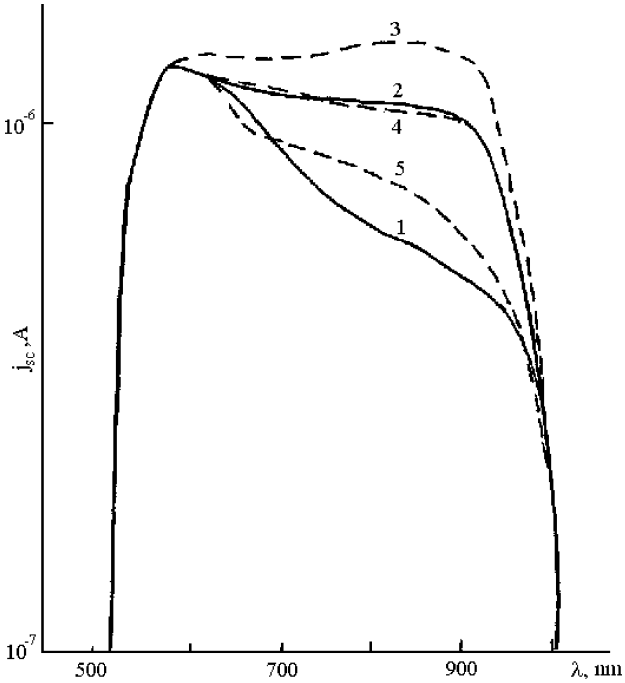

Fig. 2. Spectral dependence of short-circuit current of CdS-Cu_2S heterophotocell. Curves 1 and 2 are experimental ones obtained at absence and presence of intensive illumination $\lambda < 520$ nm. Curves 3, 4, 5 calculated for values L_n: 1.0; 0.35; 0.05 μm, respectively.

Such value of diffusion length agrees well with high EMF of research photocells and results of direct electronic microprobe measurements. So, the investigations carried out indicate that application of curves I_{sc} and $\alpha(\lambda)$ allows to determine for sure the length of minority carriers in non-ideal heterojunctions. But for this case one should provide the constancy in enrichment factor of carriers in heterojunction.

Measurements by the described procedure were made for obtained photocells moreover the value L_n in Cu_2S for most of them did not fluctuate very sharply (0.2—0.4 μm). It follows that thickness of cooper sulphide film more than

0.5 μm does not lead to the essential increase of carrier collection there, but strongly hinders its formation by substitution reaction. So, at photocell production one should follow the obtained optimal thickness of CdS-Cu_2S layer (0.6 μm—0.8 μm).

So, to define diffusion length of minority carriers in cooper sulphide by spectral dependence of photocurrent one should provide the steady-state conditions for their collection independently on photoexcitation wavelength. Such conditions could be provided by strong additional illumination within the range of intrinsic absorption for cadmium sulphide. The obtained values of Ln for different samples were 0.2—0.4 μm.

References

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ЭФФЕКТ КОРОТКОВОЛНОВОЙ СТИМУЛЯЦИИ ФОТОТОКА И ОПРЕДЕЛЕНИЕ ДИФФУЗИОННОЙ ДЛИНЫ НЕОСНОВНЫХ НОСИТЕЛЕЙ В Cu_2S

Важнейшим параметром, определяющим эффективность собирании носителей, а, следовательно и эффективность работы фотопреобразователя, является диффузионная длина неосновных носителей в материале, где происходит основное поглощение света. Для неидеального гетероперехода CdS-Cu_2S наиболее существенной является величина диффузионной длины для электронов L_n в Cu_2S. В данной работе предложен неразрушающий метод определения диффузионной длины в этом материале.

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ЕФЕКТ КОРОТКОХВИЛЬОВОЇ СТИМУЛЯЦІЇ ФОТОСТРУМУ І ВИЗНАЧЕННЯ ДИФУЗІЙНОЇ ДОВЖИНИ НЕОСНОВНИХ НОСІЇВ В Cu_2S

Найважливішим параметром, що визначає ефективність збирання носіїв, а, отже і ефективність роботи фотоперетворювача, є дифузійна довжина неосновних носіїв у матеріалі, де відбувається основне поглинання світла. Для неідеального гетеропереходу CdS-Cu_2S найбільш істотною є величина дифузійної довжини для електронів L_n в Cu_2S. У даній роботі запропоновано неруйнівний метод визначення дифузійної довжини в цьому матеріалі.