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Influence of internal parameters on the signal value in optical sensor based on the non-ideal heterostructure $CdS\text{-}Cu_2S$

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Abstract. The signal (defined by conductivity) of optical sensor based on $CdS\text{-}Cu_2S$ heterostructure both at direct and alternative current strongly depends on barrier parameters that can change under exposure. It was stated that such parameter as resistance of space charge region considerably depends on its width at a constant barrier height, and this dependence is similar to linear shape. This behavior can indicate domination of tunnel multistep mechanisms in the studied structure, for instance, the mechanism of tunnel-jumping conductivity.

Keywords: heterojunction element, tunnel-jumping current transport, signal processing.

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1. Introduction

Basic photoelectrical characteristics of non-ideal heterojunctions cannot be explained without assumption that mechanisms of current transfer through the space charge region (SCR) differ from the thermal emissive ones and play the distinctive role [1-3]. These mechanisms have usually a tunnel character. The detailed study of the influence of SCR parameters on heterostructure conductivity is important in this relation, because it allows correcting the mechanism of losses in photosensors [3]. And the studies in relationship of barrier region conductivity with its width are of particular interest from the viewpoint that current transfer can have a tunnel character. In this paper, we have investigated the typical non-ideal heterojunction structure $CdS\text{-}Cu_2S$ and optical sensors based on it.

2. Experimental results and discussion

It was stated that the width of barrier that is concentrated in wide-band CdS can be effectively changed by light from intrinsic absorption region of cadmium sulphide [4, 5]. And under short-circuit current regime, the position of Fermi level in the quasi-neutral region is a constant value independent on the illumination intensity (without bias). Under these conditions, the height of barrier does not change, and the dependence of conductivity on width exceptionally of SCR can be determined.

Current-voltage characteristics (CVC) of the studied element were obtained under its exposure by light of various intensities with $\lambda < 620$ nm (Fig. 1). The curves studied at different levels of exposure corresponded to various values of the heterojunction photocapacity. It is clearly seen that differential resistance of the junction significantly decreases in the point $U = 0$ with increasing the photocapacity and, respectively, with decrease of the SCR length.

Our studies of the conductivity active component at alternating current ($f = 20$ kHz) were carried out using the compensation method. We used the alternating current bridge that measured the junction capacity, too, and amplitude of the measuring signal did not exceed 5 mV. The width of barrier was calculated for each value of photocapacity, and then the dependence of barrier conductivity or resistance on the SCR width for alternating or direct currents was obtained (Fig. 2).

In the latter case, the analysis of heterostructure resistance at zero bias determined from CVC (Fig. 1) shows that with increase of the SCR width its resistance raises both at alternating (curve 1) and direct current (curve 2). But the heterojunction resistance for an alternating current remains significantly lower than its stationary value. This situation is typical for the tunnel-jumping mechanism of current transfer. The presented curves are not exponential – they demonstrate a weaker dependence that approaches rather to the linear one, indicating rather the multistep mechanism of current transfer than direct tunneling.

The dependences of sensor signal (and conductivity respectively) on value of applied bias are presented in Fig. 3 for direct and alternating currents and different levels of illumination. Though the element conductivity always rises with increasing the exposure intensity, this growth can be conditioned by different effects at large and small biases.

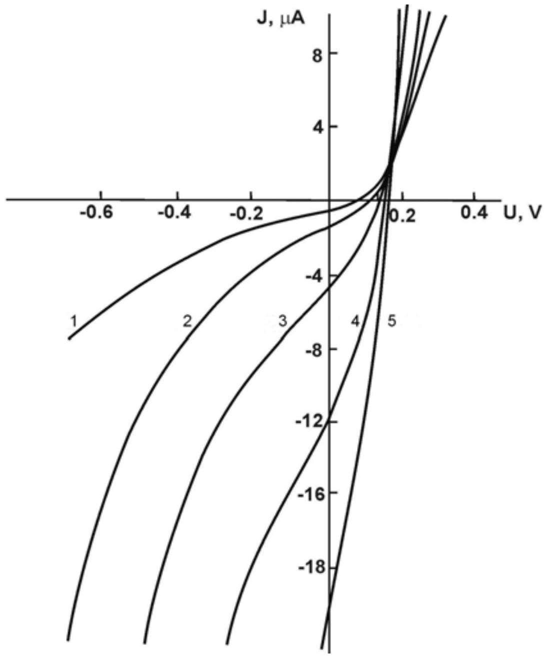

Fig. 1. Current-voltage characteristics of the CdS-Cu_2S heterojunction element for various values of the photocapacity C_{ph} (5 (*1*); 7 (*2*); 20 (*3*); 48 (*4*); 100 nF (*5*)), corresponding to various exposure levels by light from the intrinsic absorption band of CdS.

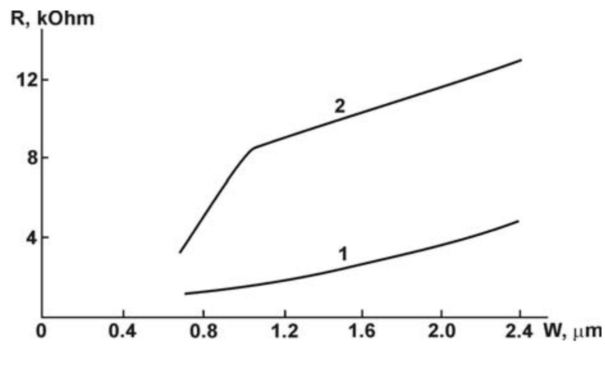

Fig. 2. Dependence of the electronic component of resistance *R* on the barrier width *W* for direct (curve *1*) and alternating (f = 20 kHz, curve *2*) currents.

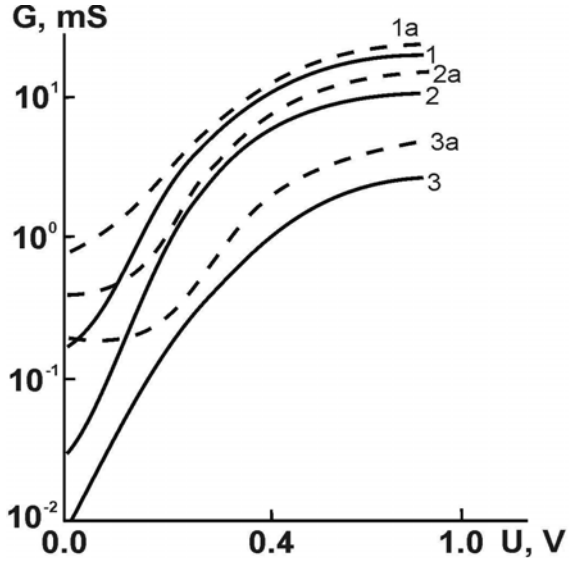

Fig. 3. Dependence of the component conductivity *G* (as a signal parameter) for direct (solid curves) and alternating (dotted curves) currents on the value of positive bias *U* under various illumination levels (*1* and *1a* – 100 rel. un.; *2* and *2a* – 20 rel. un.; *3* and *3a* – 2 rel. un.).

Fig. 3 shows that the signal values for direct and alternating currents at relatively high biases differs less, than at the lower ones. It can indicate that, with increase of the internal steady-state voltage, the current is considerably limited by the series resistance of basic CdS layer, which conductivity is controlled by free carriers, is not related with transfer over the localized states and thereof independent on the frequency of measuring signal. Observed saturation in characteristics $G = G(U)$ at biases being closer to the value of barrier height indicates the same behavior. Under high intensities of exciting light, the transition in current-voltage dependence to the ohmic shape takes place at lower biases. The growth of conductivity (as a signal value) at exposure and high voltages is probably caused by increase in conductivity of the basic CdS layer, while for low voltages – by raise in the conductivity of barrier region due to decrease in the SCR width. As it has been noted before, the amplitude of measuring signals was units of millivolts, i.e. it was significantly lower than the voltages of the external bias, and the measuring signal had no influence on barrier parameters.

Without the external bias, the difference between conductivity for direct and alternating currents is maximal, because in this case the flowing current is controlled almost exclusively by the height and width of barrier. And conductivity of barrier can be conditioned by the frequency-dependent mechanism of transfer over the localized states [5]. This shape of $G = G(U)$

relationship can lead to anomalous capacitance-voltage characteristics for the investigated element at positive biases, because the alternating signal is redistributed between different layers of the component of junction resistance decrease with increase of the applied direct voltage.

3. Conclusion

Thus, photoconductivity defined signal value depends not only on the height but on width of barrier and can be controlled by the tunnel-recombination mechanism of transfer under rather low biases. The conductivity of the non-ideal heterostructure element both at direct and alternating currents strongly depends on barrier parameters that can change under light exposure. This relation indicates predominance of tunnel mechanisms in current transfer inside the studied optoelectronic component.

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