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A New Structure of the CdS-Based Surface-Barrier Ultraviolet Sensor

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Abstract—High-resistivity CdS or ZnSe layers were grown in the CdS surface region during sensor fabrication. The results of comparative investigations are presented for known CdS ultraviolet sensors and $Cu_{1.8}S$–CdS junctions with interlayers. The layers incorporated in the space-charge regions reduce the tunnel diode currents by more than three orders of magnitude, with the high quantum efficiency of the structures being retained in the ultraviolet spectral region. © *2001 MAIK "Nauka/Interperiodica".*

The $Cu_{1.8}S$–CdS photoconverters are the most sensitive sensors of ultraviolet (UV) radiation. Having a high quantum efficiency, the CdS sensors rank below the best surface-barrier structures in electric parameters. In this paper, we report the results of developing and investigating a photoconverter structure, which makes it possible to considerably improve electrical characteristics of the CdS sensor while retaining a high photosensitivity.

The $Cu_{1.8}S$–CdS photoconverter constitutes a polycrystalline layer of cadmium sulfide onto which copper sulfide (its stable modification is $Cu_{1.8}S$ [1–5]) is sputtered in vacuum. Thicknesses of CdS and $Cu_{1.8}S$ layers are 7 μm and 15 nm, respectively. The structure indubitably incorporates a surface barrier: a pulling electric field is almost completely concentrated in the CdS photosensitive component owing to a strong asymmetry of conductivity (a hole concentration in $Cu_{1.8}S$ is $p = 5 \times 10^{21}$ cm^{-3} and an electron concentration in CdS is $n = 10^{15}$ cm^{-3}). The samples are illuminated from the $Cu_{1.8}S$ side. It should be stressed that, in contrast to the Schottky diodes, a highly degenerate $Cu_{1.8}S$ is used instead of a metal. The basic advantage of using a highly degenerate semiconductor consists in the possibility of the practicality of the photoeffect associated with generation of hot charge carriers [5]. Unsatisfactory electrical parameters of sensors are the consequence of the tunnel current shunting a junction. A high probability of dominance of the tunnel processes is caused by the multistage tunneling with the participation of deep levels in the space-charge region (SCR) [2–4].

In this paper, we propose to incorporate a thin ($\lesssim$0.1 μm) layer of a less defective material into the SCR for blocking the tunnel component. This is possible, for example, by introducing a high-resistivity CdS layer with a composition approaching the stoichiometric one in the SCR. Thus, the probability of tunneling is expected to be reduced as a result of the decreasing number of defects participating in the process of forming the tunneling current.

In correspondence with the above, we fabricated the following structure of the basic photosensitive layer. A low-resistivity ($n = 10^{15}$ cm^{-3}) CdS layer ~7 μm thick was grown on a metallic substrate by the quasi-closed-volume method; thereafter, a high-resistivity ($n = 10^{13}$ cm^{-3}) CdS layer $\lesssim$0.1 μm thick was deposited; a low-resistivity CdS layer was then grown again. On the structure obtained, a barrier-forming $Cu_{1.8}S$ film was deposited. The SCR extent was ~0.7 μm. The thickness of the high- and low-resistivity layers were ~0.1 μm; i.e., they were completely within the SCR.

In the case of CdS sensors, the interlayer blocking the tunnel component of current can also be formed from zinc selenide (a wide-gap II–VI compound). Actually, the ZnSe high-resistivity layer deposited in the common technological cycle can be obtained without violating the basic parameters of the technological process of depositing CdS. In addition, it is of prime importance that ZnSe forms a continuous series of solid solutions $(CdS)_x(ZnSe)_{1-x}$ with CdS [6]. Thus, growing ZnSe on CdS with a transition variable-gap layer, we can prevent the formation of additional defects in the SCR associated with a mismatch between the crystalline lattices of ZnSe and CdS.

The photoconverter with a ZnSe intermediate layer was fabricated similar to those described above with the mandatory growth of the low-resistivity layer. The role of the low-resistivity interlayer was discussed previously [7, 8]. The main requirements to this layer are the following: it must be reasonably thin to avoid screening the contact difference of potentials as well as to provide the sufficient pulling electric field near the illuminated surface and, consequently, to preserve a high quantum efficiency.

Below, we report the results of comparative investigations of the $Cu_{1.8}S$–CdS junctions obtained using the

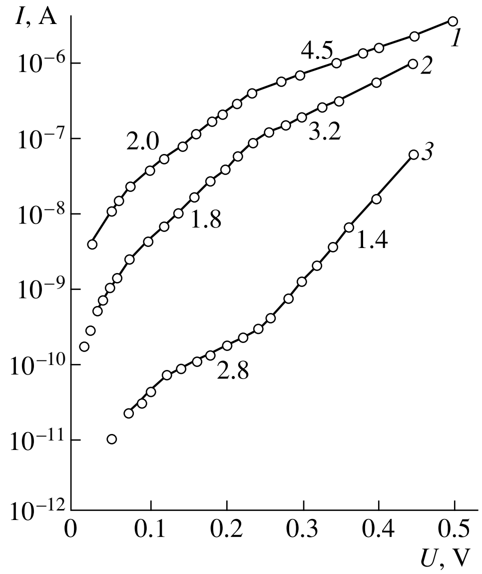

Fig. 1. Forward current–voltage characteristics of the $Cu_{1.8}S$–CdS junctions: (*1*) without intermediate layers, (*2*) with high-resistivity CdS layer, and (*3*) with a ZnSe layer. Values of β are indicated.

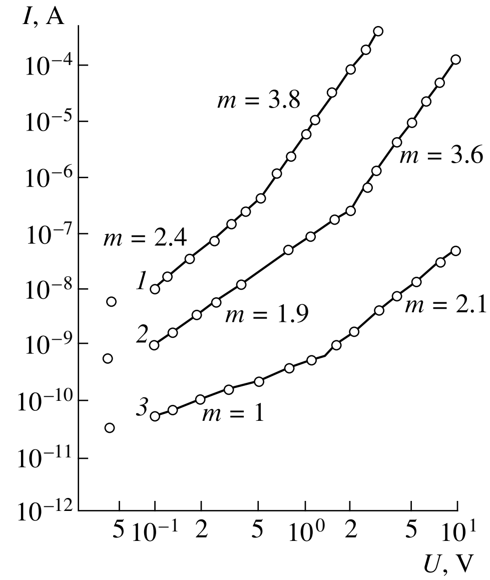

Fig. 2. Reverse current–voltage characteristics of the CdS sensors: (*1*) without intermediate layers, (*2*) with an intermediate high-resistivity CdS layer, and (*3*) with an intermediate ZnSe layer.

known technologies [1–5, 7, 8] and the $Cu_{1.8}S$–CdS junctions with high-resistivity interlayers. We studied the forward and reverse current–voltage (*I*–*V*) characteristics $I(U)$ and the spectra of external quantum efficiency $Q(\lambda)$.

In Fig. 1, we show the forward *I*–*V* characteristics, which can be functionally written as $I = I_0\exp(\alpha U)$, where $\alpha = e/\beta kT$ if the thermal processes are dominant. Values of β (shown in Fig. 1) for curves *1* and *2* and an unusual variation in the slope of the *I*–*V* characteristic on the semilogarithmic scale (when the slope of straight lines decreases instead of increasing with the forward voltage) are typical of the junctions with p-$Cu_{1.8}S$ [2] in which the recombination–tunneling currents are prevalent. The presence of a high-resistivity CdS layer in the SCR reduces the shunting currents almost by an order of magnitude compared to the structure without a high-resistivity CdS layer (curves *2* and *1*, respectively).

The aforementioned currents decrease by more than three orders of magnitude if a ZnSe interlayer is used. Furthermore, as can be seen from Fig. 1 (curve *3*), for bias voltages $U > 0.3$ V, the overbarrier dark currents for which $\beta = 1.4$, $I_0 < 10^{-12}$ A (the sample surface area is 25 mm^2) prevail.

Special features of the reverse *I*–*V* characteristics (Fig. 2) are also indicative of a decrease in the currents as a result of the decreasing probability of tunneling. For the reverse *I*–*V* characteristics, the current can be written as $I \propto U^m$. In Fig. 2, two portions with parameters of *I*–*V* characteristics inherent in the junctions of this type [3] are observed for straight lines *1* and *2*: prebreakdown portions with $m = 1.9$–2.4 and the portions of soft tunnel breakdown with $m > 3.5$. When the ZnSe interlayer is used, there is no tunnel breakdown ($m < 3$, curve *3*) up to the bias voltage $U = 10$ V. For these structures, the generation currents with $m = 1$ are dominant up to $U = 1$ V. As can be seen from Fig. 2, for $U = 1$ V, the current decreases by four orders of magnitude compared to the junctions without the high-resistivity interlayers (curve *1*).

In Fig. 3, we show the spectra of the external quantum efficiency of CdS sensors. Curve *1* is a typical spectrum for efficient CdS-based photoconverters. Curves *2* and *3* are the spectral distributions of sensitiv-

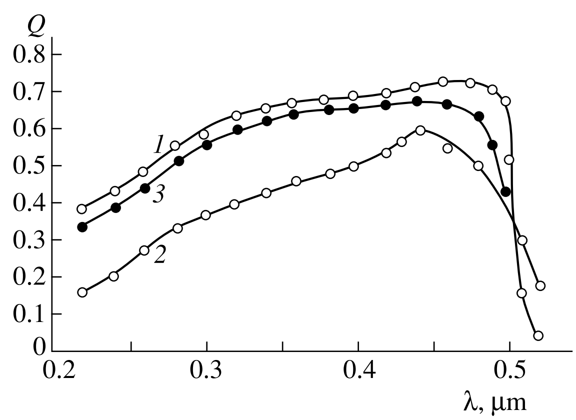

Fig. 3. Spectral distribution of quantum efficiency $Q(\lambda)$ for the $Cu_{1.8}S$–CdS surface-barrier sensor: (*1*) without high-resistivity intermediate layers, (*2*) with a high-resistivity ZnSe layer, and (*3*) with a low-resistivity layer and a ZnSe layer.

ity of junctions with only the high-resistivity ZnSe and the photoconverters with intermediate high-resistivity ZnSe and low-resistivity CdS layers, respectively. It can be seen that the presence of the low-resistivity surface layer considerably enhances the quantum efficiency within the entire spectral region.

Thus, the investigations of the *I–V* characteristics and the spectra of quantum efficiency show that the consecutive growth of high- and low-resistivity layers arranged in the SCR of the surface-barrier contact makes it possible to considerably improve the electrical parameters and to retain a high quantum efficiency of the CdS sensors. It should be stressed that the *I–V* characteristic parameters attained in this study for the thin-film polycrystalline structures do not rank below those inherent in the best single-crystalline analogues. A high photosensitivity and optimal electrical characteristics close to the limiting ones make the developed structures the best among the known UV sensors.

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