THIN FILM ZnTe-CdTe POLYCRYSTALLINE HETEROJUNCTIONS WITH AN INTERMEDIATE Zn$_x$Cd$_{1-x}$Te LAYER

P. Gasin, V. Feodorov, L. Dmitroglo

State University of Moldova, Department of Physics, Str. A. Mateevici 60, Chisinau, MD-2009, e-mail: gashin@usm.md

Cadmium telluride with the band gap of 1.45 eV, corresponding to solar radiation maximum, is a semiconductor of direct optical transitions and high values of charge carrier mobility. Solar cells based on pZnTe-nCdTe heterojunctions are of great interest, their theoretical efficiency is ~ 17%. However the lattice mismatch of the components leads to the formation of surface states of the density $N_s \sim 10^{13}$-$10^{14}$ cm$^{-2}$ at the heterojunction interface, which strongly affect its physical properties [1]. $N_s$ could be considerably lowered by creation of an intermediate layer of Zn$_x$Cd$_{1-x}$Te solid solution [2].

TECHNOLOGY OF ZnTe-CdTe HJ FABRICATION

Two groups of thin film polycrystalline ZnTe-CdTe heterojunctions were fabricated by “hot wall” method. To the first group (HJ1) HJ are related without especial design of the transition region at the interface. The second group samples (HJ2) present a three layer structure with an intermediate layer of Zn$_{0.4}$Cd$_{0.6}$Te solid solutions at the interface. ZnTe layers of thickness $d=2$-$3 \mu$m were grown simultaneously with their doping by Cu on glass substrates covered with SnO$_2$ electrode. The growth rate was $0.05 \mu$m/min. Onto ZnTe layer an additional thin ($d=0.5$-$1 \mu$m) layer of Zn$_{0.4}$Cd$_{0.6}$Te solid solutions was grown. After that the deposition of CdTe ($d=4$-$6 \mu$m) layer was carried out. CdTe layers were doped with In. Consequently, ZnTe-CdTe heterojunctions represent a planar structure. Indium evaporated in vacuum was used as an ohmic contact to n-CdTe and SnO$_2$ transparent conducting layer as an ohmic contact to p-ZnTe.

DIRECT I-V CHARACTERISTICS

The temperature dependence of I-V characteristics of both heterojunction groups was studied. It was established that at $T>320$ K for HJ1 and $T>250$ K for HJ2 the direct I-V characteristics are satisfactory described by the equation:

$$I = I_s \exp(eU/\beta kT), \quad (1)$$

where the diode factor $\beta=2$, $I_s$-saturation current. Using equation (1) for describing I-V characteristics in the low temperature range ($T<200$ K for HJ1 and $T<250$ K for HJ2) corresponded to the value $\beta>2$, hence the current flow in this temperature range was determined not by the thermoactivational processes [5], but is controlled by the tunneling at least in a part of the space charge region (SCR). Therefore the experimental results more correspond to the relation:

$$I = I_s \exp(BT) \exp(AU), \quad (2)$$

where $A$ and $B$- are constants independent of temperature and bias voltages. Their values were $A=12V^{-1}$, $B=5\cdot10^{-2}$ K$^{-1}$.

The diode factor value indicates the prevailing in the current flow of emission-recombination mechanism in the Schockley-Noyce-Sah model [6]. According to this model when the direct bias is applied to p-n junction the charge carrier concentration in the SCR is high and the recombination processes in the region, where $p\approx n$ are considerable.

The shift of current flow mechanism with the temperature from emission-recombination to tunneling is related to the exponential decrease of intrinsic concentration, determined by the recombination rate in Schockley-Noyce-Sah point. Therefore at low temperatures the named recombination channel can come to saturation, and further recombination processes on the interface states. Moreover the principal type of tunneling in SCR, apparently is thermal tunneling. The tunneling at the potential barriers base is less probable, because the minority carrier diffusion length value in II-VI compounds is $L_n>L_p<0.5 \mu$m [7], which is less than SCR width.
Temperature dependence on the direct I-V characteristics for a sample of HJ2 is given in Fig.1. One can see, that its characteristics have a distinctly diode feature. At t=300 K and biases U=1V the rectification coefficient values of 6-10^3. The extrapolation of the direct dependences to I=0 the “cutting off” voltages was determined. At 300K they were 0,8 V, and at 90 K, 24 V. The temperature dependence of diffusion potential was approximated by the relation:

\[ U_{\text{cut-off}}=U_{o}-\alpha T, \]  

(3)

Where the temperature coefficient value was \( \alpha =2,1\cdot10^{-3} \) V/K. One should mention, that the diffusion potential values of HJ2 are higher than for HJ1.

The direct I-V characteristics at \( U<U_{\text{cut-off}} \) in the whole temperature range of investigation (90-400 K) have an exponential dependence (Fig.2), and in the low temperature region (T<250 K) they have a constant slope, not depending on temperature. In this temperature region the exponential segment is described by the relation (2), characteristic of the tunnel current flow. Beginning from \( T\approx250 \) K the exponential segment slope became temperature dependent and I-V dependences can be given by the equation (1) for emission-recombination current flow. In the temperature range \( 250K<T<400K \) the diode factor \( \beta \) varies from 1,97 to 1,41. At room temperature its value is 1,57.

The \( \beta \) temperature dependence is typical for wide band gap II-VI compounds [6]. According to Schockley-Noyce-Sah theory considering generation-recombination process through a single level center in SCR \( \beta=2 \) and does not change with temperature [8]. The revealed peculiarities witness about the thermoinjectional recombination mechanism through multilevel center [9], for which the temperature independent parameter has the value of \( 1<\beta<2 \). The current flow mechanism shift is confirmed by the saturation current \( I_s \) temperature dependence. The experimental data for \( T>250 \) K are fitting \( \lg I_s=f(1/T) \) straight line (insertion to Fig.2). The barrier height, determined from the saturation current temperature dependence in this temperature region was \( \Delta E_A=0,83 \) eV. One can see, that activation energy value of saturation current coincides with a good accuracy with the value of “cut off” voltage.

**REVERSE CURRENTS**

The reverse currents were studied in the same temperature range as the direct ones. The applied biases did not exceed 12 V to avoid the unreversed threshold. Based on the experimental data for both HJ groups, a supposition about thermo-tunneling current flow mechanism was made [10]. It is
supposed that the electrons of p-ZnTe valence band are transferred to a local center in SCR, from where they are either thermally thrown or tunneled into CdTe conduction band. The thermal component of the reverse current is flowing in series with the tunnel one. Their ratio is determined by the temperature, applied bias and generation center concentration in SCR.

In the double logarithmic scale the reverse I-V dependences consist of two segments, each of them could be described by the power dependence:

\[ I_{\text{rev}} = C U^m \]  

(4)

The break corresponds to the mild “threshold” voltage \(U_{\text{thr}}\) and is determined by the interface state in HJ. The analogical dependence was observed for power index \(m\) and the value of \(U_{\text{thr}}\). Indeed, at 300 K on the first segment \((U < U_{\text{thr}})\) \(m=0.8-1.1\) for both HJ groups, and on the second segment \((U > U_{\text{thr}})\) a stronger \(I_{\text{rev}}(U)\) dependence, where \(m=6, U_{\text{thr}}=1.5\) V for HJ1 and \(m=1.5 U_{\text{thr}}=3\) for HJ2 was observed.

The contribution of the thermal component in the reverse current increased with temperature increase. This was expressed in the decrease of I-V dependences slope on both segments. For HJ1 with temperature increase from 90 K to 400 K the power index \(m\) decreased from 1.5 to 0.7 on the first segment and from 6 to 1.8 on the second segment. The contribution of the tunnel component increased with the reverse bias increase and as a result a break in the point of \(U_{\text{thr}}\) was observed. The presence of tunnel component on the first segment of I-V dependence is confirmed by weak exponential dependence \(I_{\text{rev}} \approx \exp(BT)\), where \(B=4.2 \times 10^{-3} \text{ K}^{-1}\) for HJ1 at \(U=0.7\) V.

The analysis of “mild” threshold voltage temperature dependence shows, that the tunneling processes in HJ1 are prevailing at \(T< 300\text{K}\). At the same time in HJ2 they become considerable at \(T< 240\text{ K}\). In our opinion this to a considerable extent is determined by higher comparable to HJ2 concentration of surface states on ZnTe-CdTe interface. The following indicates in favor of this: first, that in HJ1 the saturation current \(I_o\) more than by an order of magnitude exceeds \(I_o\) in HJ2. On the second hand the “mild” threshold in them occurs at lower reverse biases. Indeed, presence of the Zn\(_x\)Cd\(_{1-x}\)Te solid solution buffer layer in HJ2 leads to the formation of an isotype p-ZnTe-p-Zn\(_x\)Cd\(_{1-x}\)Te interface and of an unisotype p-Zn\(_x\)Cd\(_{1-x}\)Te-n-CdTe interface. It is clear, that the surface states at the second interface are rendering the determining influence on the charge transfer, their concentration should be considerably higher, than at the first one.

The reverse I-V dependences of HJ2 structure measured at different temperatures are given in Fig.3. I-V dependence consists of two power dependence segments. However on the second \((U > U_{\text{thr}})\) there is stronger \(I_{\text{rev}}(U)\) dependence. The current temperature dependence on both I-V segments had an activational nature (curves 1,2 on the insertion). From the figure one can see, that activation energy practically does not depend on the bias: \(\Delta E_A(U=1\text{V}) \approx \Delta E_A(U=6\text{V})=0.77\) V. Their values are comparable with the activation energy, determined from direct I-V dependences. This allows to suppose the participation of the same deep centers in the charge transfer at direct and reverse biases.
PHOTOELECTRICAL PROPERTIES

The studied heterojunctions were characterized by a high photosensitivity in the wavelength region of 550-850 nm. The spectral dependences of short circuit current at 300K for HJ1 and HJ2 structures are given in Fig.4a. Spectral dependence of HJ1 (curve1) consists of two unstructured bands, limited by the photons energies close to CdTe and Znte band gaps. However, the most efficient charge carrier separation occurred in the heterojunctions with an intermediate layer. The wide photosensitivity band of HJ2 with the maximum at $\lambda=700$ nm (curve 2) reflected the contribution of the charge carriers generated in Zn$_x$Cd$_{1-x}$Te layer to the photovoltaic effect.

The temperature variation leads to the considerable photoresponse spectra reorganization. The $I_{sc}$ spectral distribution at 77 K is brought in Fig.4b. One can see that at such temperature the photosensitivity in the long wavelength region of spectra increases. This is related to the displacement of SCR in CdTe. The photoresponse increase in the short wavelength region of spectra for HJ1 sample, can be related to the minority charge carrier diffusion length increase in ZnTe.

The presence of the intermediate layer provided the best photovoltaic characteristics of ZnTe-CdTe heterojunction. In photoconverters based on such structure the following parameters were obtained: $V_{o.c} \approx 0.8$V and $I_{sc} \approx 6$ mA/cm$^2$, AM2. These values are considerably higher than for traditional ZnTe-CdTe heterojunction, which under the same conditions were: $V_{o.c} \approx 0.7$V and $I_{sc} \approx 4$ mA/cm$^2$.

REFERENCES