Free carriers and extended defects exchange interaction in heterojunction region

B.A. Orlowski[1], K. Gwozdz[2], K. Goscinski. , S. Chusnutdinow[1], E. Guziewicz[1]. B.J. Kowalski[1]

[1]*Institute of Physics, Polish Academy of Sciences, Al. Lotnikow 32/46 ,Warsaw, Poland*

[2]*Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland*

Carriers generated by illumination of junction lead to the remarkably higher change of relative concentration for minority than for majority carriers. This is causing bigger shift of quasi Fermi level energy of minority than of majority carriers. In steady state the difference of these energies shift of opposite sides of the photovoltaic element contribute to the value of generated open circuit voltage. Measured spectra of the generated open circuit voltage versus light intensity of photon bunches allow to scan the wide part of the band gap energy region by the quasi Fermi level of minority carriers. The defects located in the scanned band gap region contribute the steps shape of the measured open circuit voltage spectra. It allows to determine the defects binding energy position located in forbidden gap.

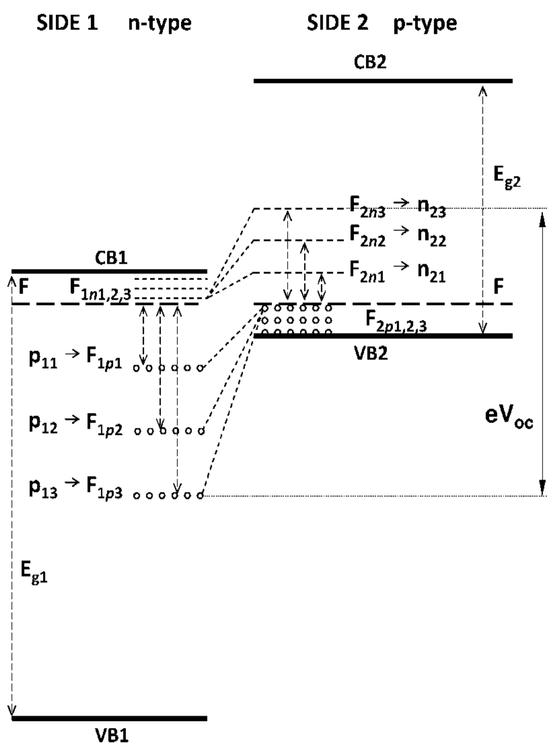

Fig. 1. The sequential changes of generation values on p_{11}, p_{12} and p_{13} leads to the corresponding changes of holes quasi Fermi level value equal F_{1p1}, F_{1p2}, and F_{1p3} and small changes for majority electrons $F_{1n1,2,3}$). In analogy, for side 2, the changes of generation n_{21}, n_{22}, n_{23} leads to the corresponding changes of electrons quasi Fermi levels positions F_{2n1}, F_{2n2}, F_{2n3} for minority carriers electrons and to small changes of $F_{2p1,2,3}$ for majority carriers holes.

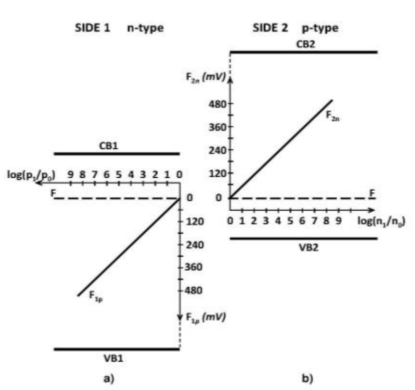

Fig. 2a. The increases of quasi Fermi level of minority carriers F_{1p} and F_{2n} with increase of the minority carriers concentration. For kT=26meV and $\ln(n_1/n_0)=\ln 10=2.303$ we have $F_{2n}=(kT)\ln(n_1/n_0)$ =~ 60 meV

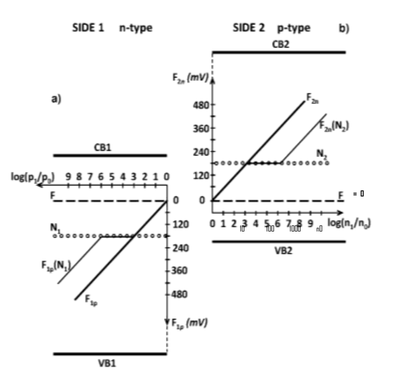

Fig. 2b. The defect recombination centers N_1 or N_2 are damping values of generated minority carriers concentration and corresponding values of F_{1p} and F_{2n} and it lowers the open circuit photovoltage value.

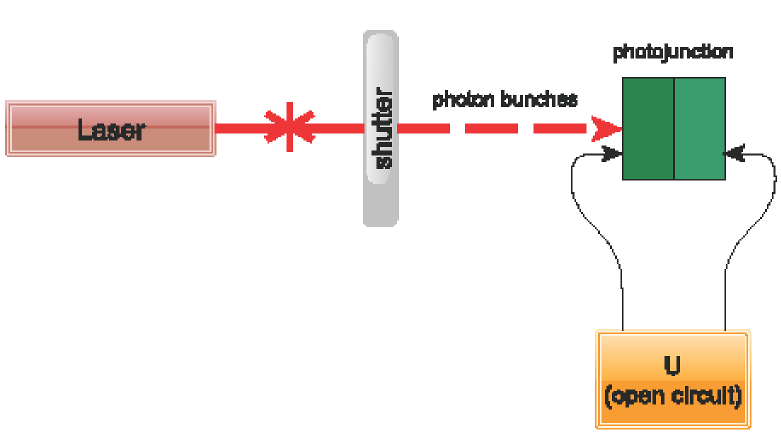

Fig. 3. Experimental Illumination and electronic set up. The time t_i of open shutter allow to increase the free carriers concentration from n_0 and p_0 to the corresponding n_i and p_i and it leads to corresponding shifts of quasi Fermi levels energy relatively on F_{ni} and F_{pi} from the F=0eV of thermal equilibrium Fermi level energy.

1. B.A. Orlowski at all, Acta.Phys.Pol. A, **134,** 590(2018).
2. S. Chusnutdinow at all, Acta.Phys.Pol. A, **126**, 1072(2014)
3. E. Zielony at all, J. Appl. Phys. **115,** 244501(2014).
4. K. Wichrowska at all, J. Appl. Phys. **123, 161522(22018)**

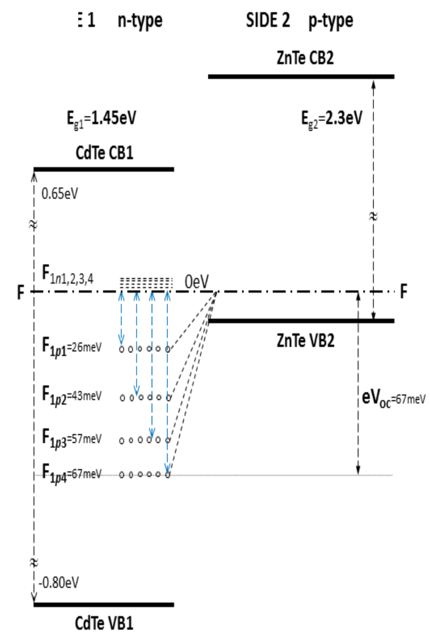

Fig. 4b. Electronic structure with the ZnTe and CdTe band gaps and common equilibrium Fermi level. The measured four defects levels (see **Fig. 5a.**) are located in CdTe band gap below Fermi level in the region from 0 down to 70meV. The states can be correlated to the dislocations extended defects in ZnTe/CdTe heterojunction [2,3].

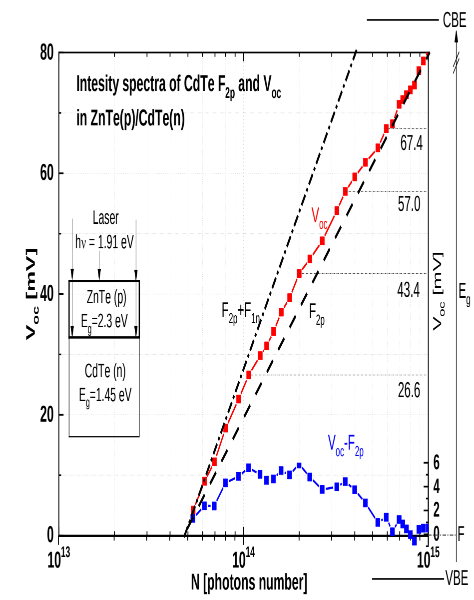

Fig. 4a. Plot of V_{oc} intensity spectra of ZnTe(p)/CdTe(n) junction. Photons of energy hv = 1.91eV, transparent for ZnTe and absorbed by CdTe (see inclusion). The red line corresponds to experimental curve, black line - predicted by model. Four V_{oc} steps (26,6; 43,4; 57,0 and 67,4meV) indicate the energy position of the defects damping generated voltage by lowering concentration of the minority carriers.

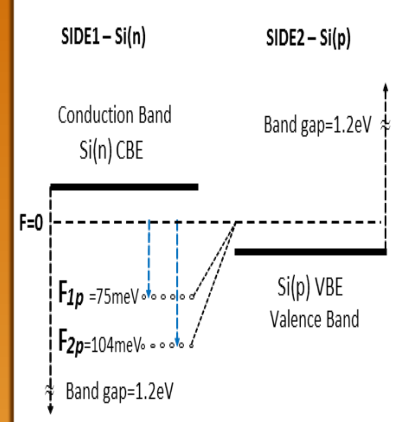

Fig. 5b. Electronic structure of band gap of Si n and Si p and common equilibrium Fermi level. The measured two steps (see Fig. 7.) are located in Si n type band gap below Fermi level. The states can be correlated to the local defects in the homojunction.

.

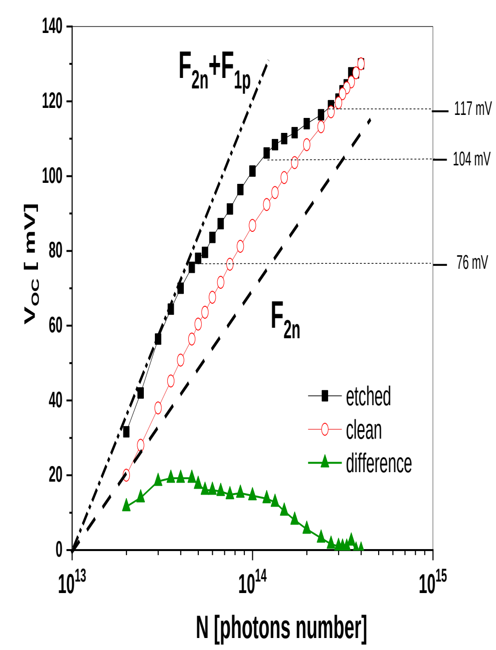

Fig. 5a. Plot of V_{oc} intensity spectra of Si p/n homojunction. The red line corresponds to perfect „clean" homojunction V_{oc}. intensity spectra. Black line corresponds to the photojunction after etching. Etched surface defects lead to effect of scattered photons harvest leading to increase of generated V_{oc} - lowest curve - difference between black and red curve. The steps on black line (76 meV and 104 meV) approximate the energy position of defect states located below F=0.

SUMMARY

- The increase of illumination photons number leads to the scan of forbidden band gap region by the quasi Fermi level Fig. (1, 2a and 2b), and the change of their energy decides on the value of the generated open circuit voltage of photojunction.
- The change of quasi Fermi level energy F_{2n} of electrons minority carriers and F_{1p} of minority holes value gave the main contribution to the generated voltage of photojunction.
- The photojunction can be treated as a double cell with contribution of voltage generated by electrons in conduction bands and holes in valence bands $V_{np} = V_n + V_p$.
- The electronic defects (e.g. extended defects, nanograin boundaries, nanoclasters, recombination or pinning centers,) created at the region of photojunction will modify linear dependence presented at Fig. (1, 2a and 2b) and creates pining steps.
- The experiment allows to estimate the energy position of pining steps relatively to the thermal equilibrium Fermi level energy position.