CHANGE OF CHARGE TRANSFER DIRECTION FOR HETERO AND PHOTO JUNCTION UNDER COMMON ILLUMINATION

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The study concerns exchange interaction of free minority carriers with defects states located in illuminated photojunction. The interaction leads to the appearance of new additional structure of measured V_{oc} illumination intensity dependence. The comparison with theoretical model illustrate the interaction results.

The thermal equilibrium Fermi level energy position F in the forbidden gap of a semiconductor determine the different concentrations of free electrons n_0 and holes p_0 in the conduction and valence bands of photojunction. In the case of the sample illumination, the same numbers of free electrons and holes are generated in the sample proportionally to the number of absorbed photons. Different conditions of exchange interaction of generated electrons and holes in the crystal lead to the creation of crystal steady state conditions and finally different relative increase of densities of free electrons n_1/n_0 and free holes p_1/p_0 in the conduction and valence bands. This steady state condition relative increase of concentrations determines the shift of Fermi level values F to new positions of quasi Fermi levels, different for free electrons and holes. These shifts, generated in the photojunction components, contribute to the open circuit voltage V_{oc}. Changes of illumination intensity allow to determine of V_{oc} illumination intensity dependence. The shift of the quasi Fermi level through the forbidden gap region can lead to the exchange interaction of free carriers with defect states [1-5] located in the gap. The direction of the of exchange interaction transfer will lead to the increase or decrease of measured V_{oc} value.

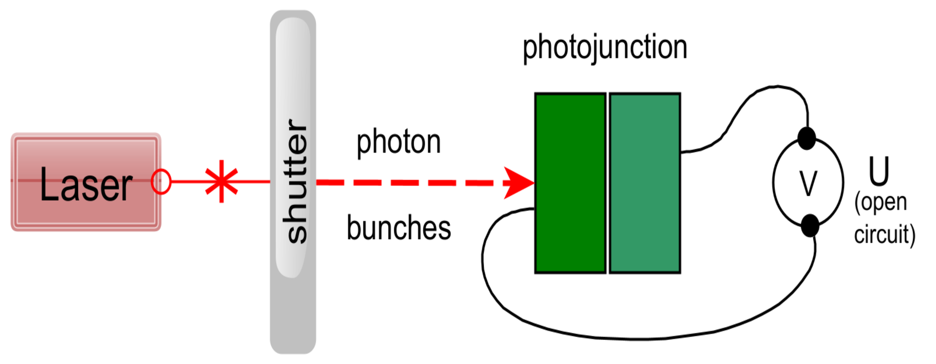

Fig. 1. The time of open shutter allow to increase of fre carriers concentration from p_{10} and n_{20} at thermal equilibrium steady state F to the corresponding p_{11} and n_{21} at steady state conditions under illumination. It leads to corresponding steps of energy shifts of the quasi Fermi levels of F_{1p1} and F_{2n1} and respectively, from F=0eV. of the equilibrium quasi Fermi level.

Illumination of photojunction ZnTe(p)/CdTe(n) of the top layer side ZnTe (E.g.=2.3eV), transparent for laser emitted photons of energy hv = 1.91eV - do not generate electrons and holes in ZnTe and generate it only in CdTe (E.g. = 1,45eV). To illustrate expected quasi Fermi level shifts values lets take concentration parameters : $n_{10}=10^{16}cm^{-3}$, $p_{10}=10^{6}cm^{-3}$, $p_{11}=10^{8}\ cm^{-3}$, $n_{11}=(10^{16}+10^{8})cm^{-3}$.

In this case we have:

For minority p: $F_{1p1}= kT\ ln(p_{11} / p_{10}) = 26meV\cdot ln100 = 120meV$,

For majority e: $F_{1n1}= kT\ ln(n_{11} / n_{10}) = 26meV\cdot ln((10^{16}+10^{8})/ 10^{16}) \sim 26meV\cdot ln(1) \sim 0$.

The energy shift of quasi Fermi level of minority carriers F_{1p1} dominates as a contribution to the generated V_{oc} value and the parameters like F_{1n1}, F_{2n1} and F_{2p1} can be neglected. Properly selected monochromatic laser radiation (photon energy and radiation intensity) allow to increase steps of quasi Fermi level of minority carriers of one side only of the junction material. It allows for more accurate study of electronic parameters of the material and (relatively) neglect influence of other material parameters of photo junction.

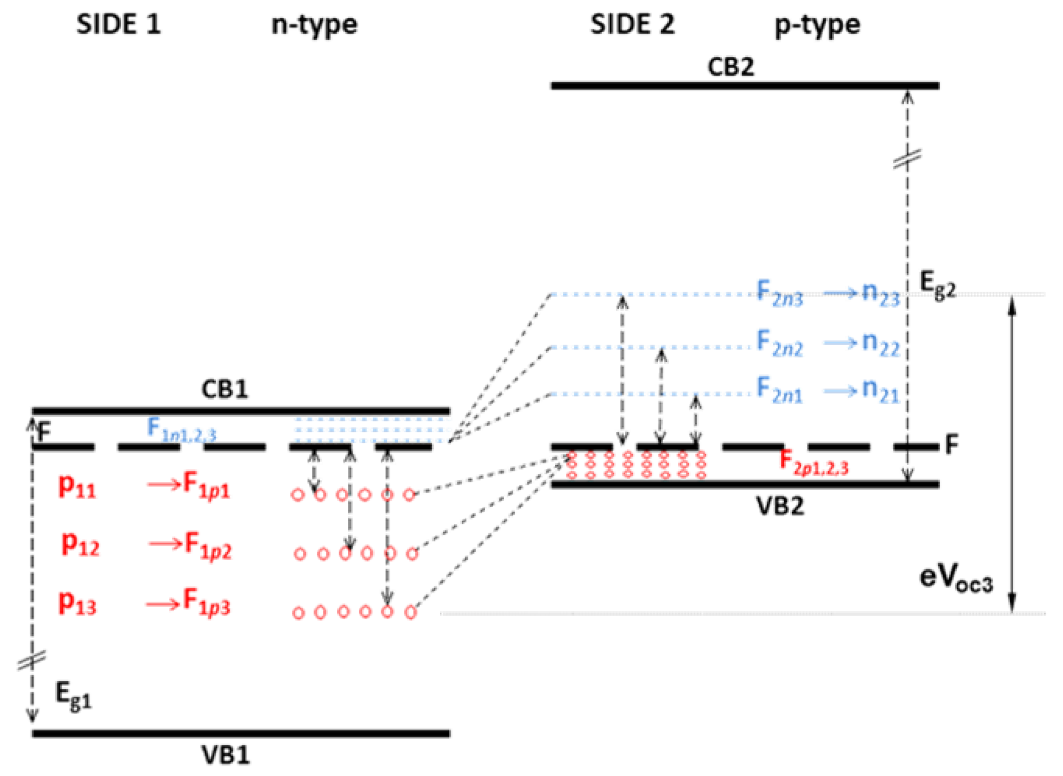

Fig. 2. The illustration of photojunction electronic structure changes under illumination. For SIDE 1 n-type, the sequential changes of generated concentration of minority holes from p_{10} to p_{11}, p_{12} and p_{13} lead to the corresponding changes of hole quasi Fermi levels value equal F_{1p1}, F_{1p2} and F_{1p3} and to relatively small changes for majority electrons $F_{1n1,2,3}$.

In analogy, for SIDE 2 p-type, the changes of generated concentration of minority electrons from n_{20} to n_{21}, n_{22}, n_{23} lead to the corresponding changes of electron quasi Fermi levels positions F_{2n1}, F_{2n2}, F_{2n3} and to relatively small changes of $F_{2p1,2,3}$ for majority hole carriers .

The generated quasi Fermi level differences for holes ($F_{1p3} - F_{2p3}$) and analogical for electrons ($F_{2n3} - F_{1n3}$) (red and blue at Fig.2) contribution to created open circuit voltage value:

$eV_{oc3} = (F_{2n3} - F_{1n3}) + (F_{1p3} - F_{2p3})$.

$F_{1p1} = kTln(p_{11} / p_{10})$; $F_{1n1} = kTln(n11 / n10)$; $F_{2p1} = kTln(p_{21} / p20)$; $F_{2n1} = kTln(n_{21} / n_{20})$

Lets take illustration of used realistic values: e.g. for minority carriers tenfold (increase of p_{10} [$ln(p_{11}/p_{10})$ = ln(10) = 2.303] and kT = 26meV) we obtain F_{1p1} = ~60meV. For majority carriers n_{10}>>p_{10} and F_{1n1} can be neglected.

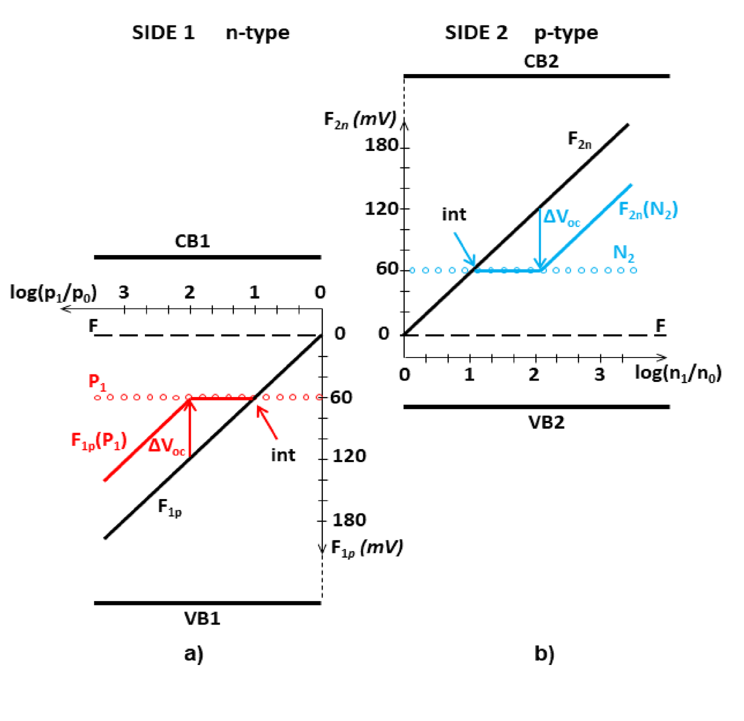

Fig. 3a,b. *Illustration of damping of V_{oc} shifts by defects concentration minority carriers.*

The introduced defects centers concentration P1 and N2 lead to the damping 0f minority carriers concentration ten times (Fig 3a and 3b from 1 – 2) and predicted by model values of V_{oc} are reduced (from $F_{1p}$to $F_{1p}(P_1)$, 120 -60Vm) by the value 60mV with change of photojunction illumination intensity.

In general, under performed illumination of the sample we can take the defects P_1 and N_1 which can be properly charged and instead of damping will supply V_{oc} value in minority carriers concentration and it will lead to V_{oc} value increase.

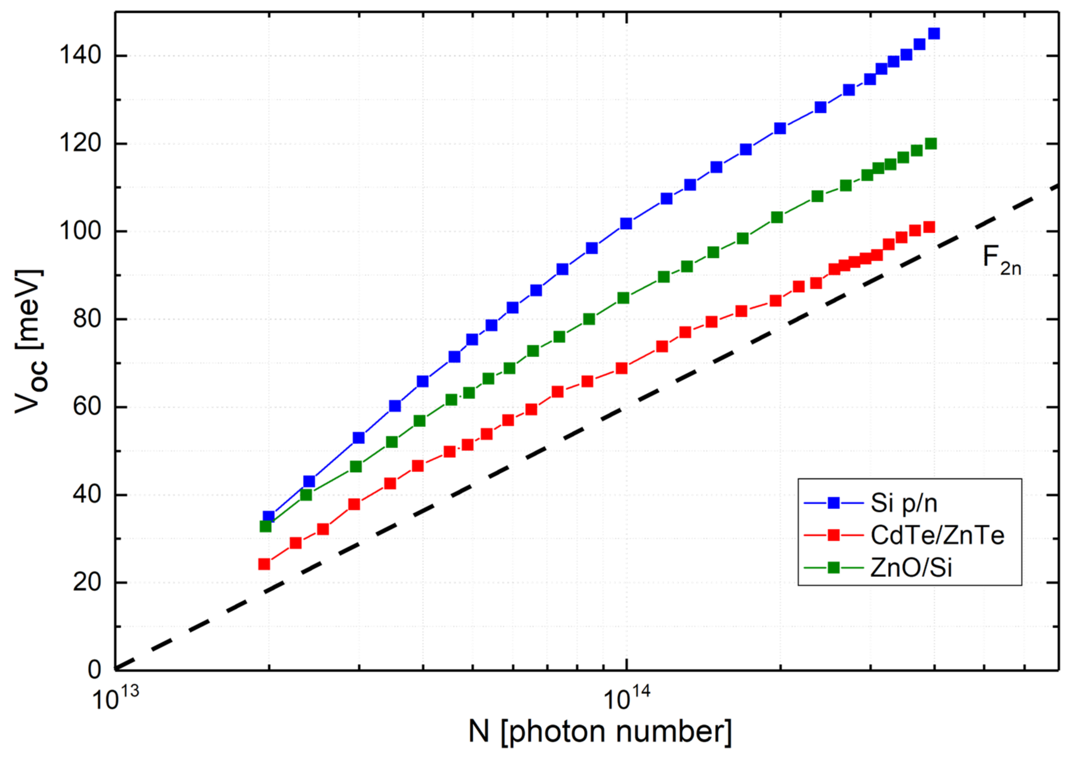

Fig.4. Plots of V_{oc} as a function of illumination for: ZnO/Si hetero-junction, Si(n/p) homojunction and ZnTe(p)/CdTe(n) heterojunction. For the heterojunctions the curves are parallel to the lower dotted line corresponding to the light absorption in only one side of junction - Si or CdTe. The other parts of the heterojunctions (ZnO or ZnTe, respectively) are transparent for the applied.

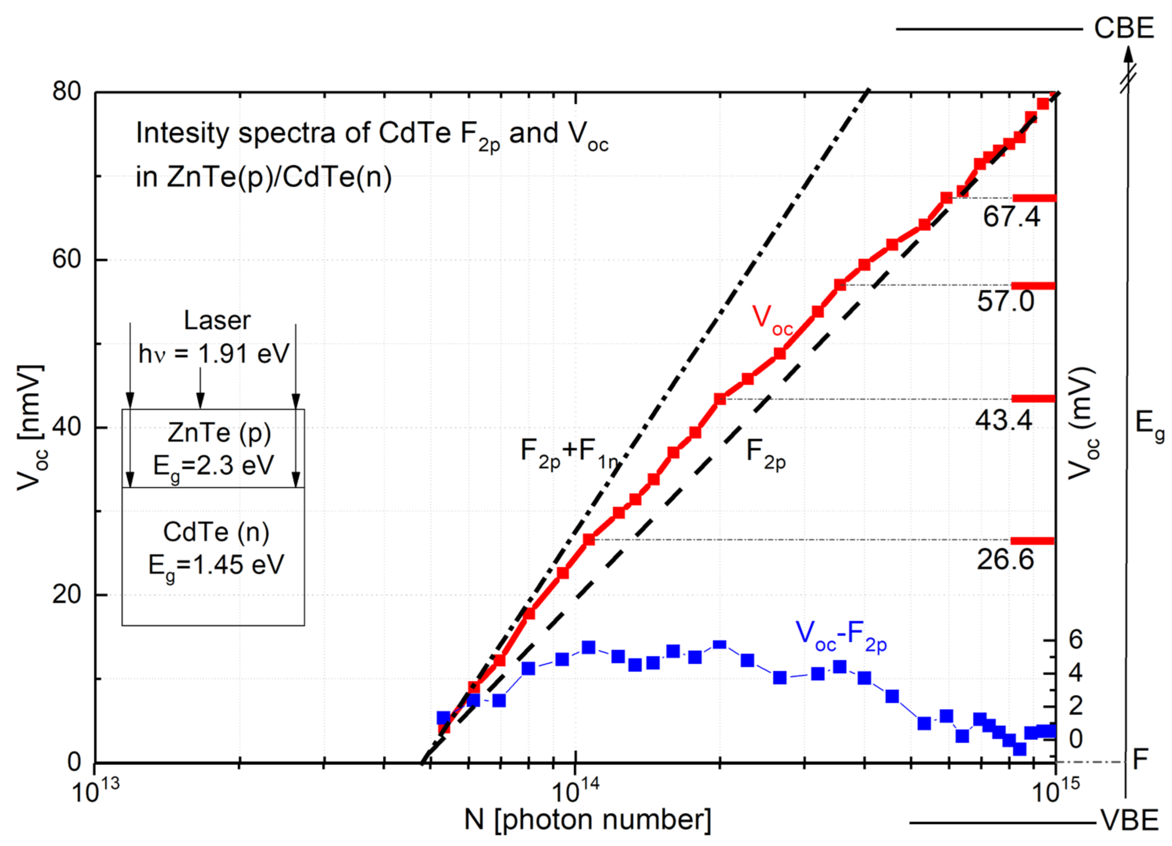

Fig. 5a. Plot of V_{oc} intensity spectra of ZnTe(p)/CdTe(n) junction. Photons of energy hv=1.91eV, transmitted through ZnTe and absorbed by CdTe (see inclusion). The red line corresponds to the experimental curve, black line - predicted by a model. Four V_{oc} steps (26.6; 43.4; 57.0 and 67.4meV) indicate the energy positions of the defects damping generated voltage by lowering concentration of the minority carriers [2,3].

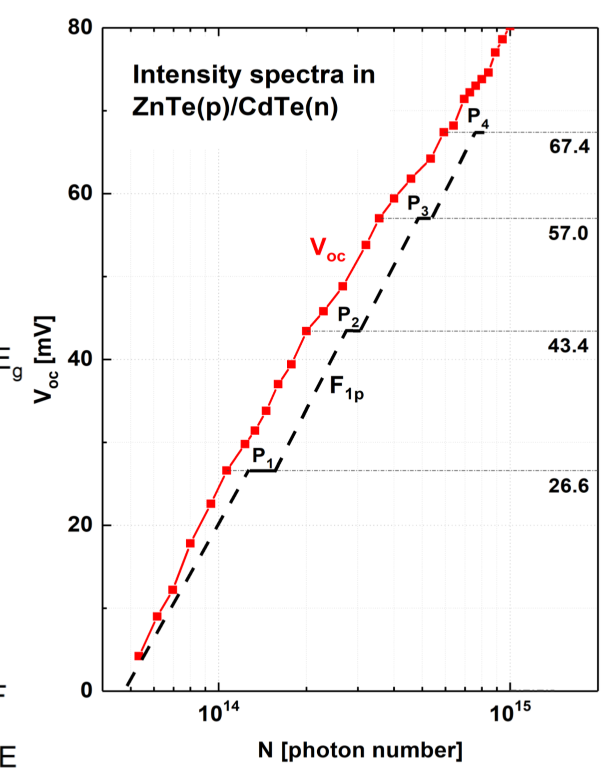

Fig. 5b. Comparison of measured V_{oc} illumination intensity dependence (red) and correlated to it model of F_{1p}(black). The steps occurs as results of exchange interaction of defect states with free carriers in the region of coincidence with quasi Fermi level F_{1p} position.

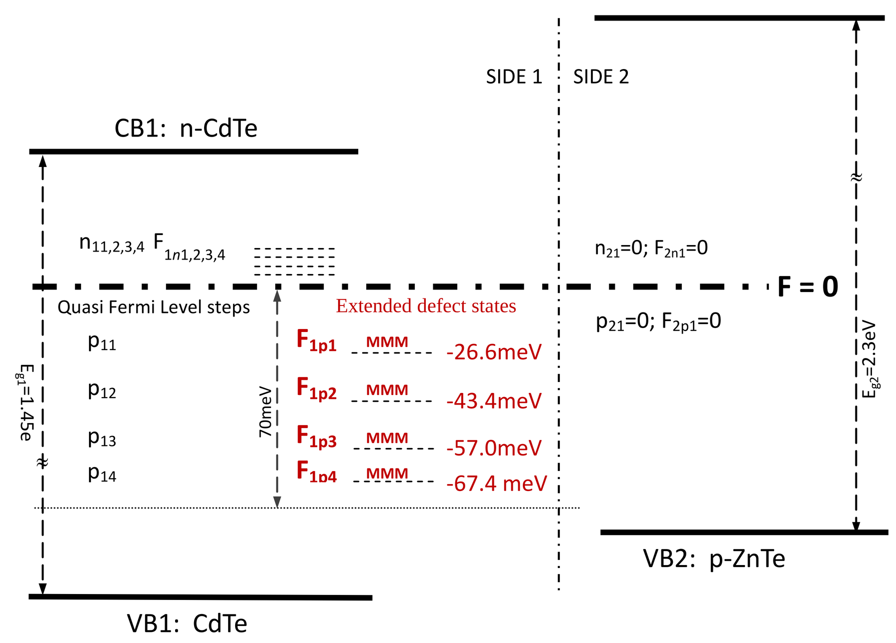

Fig. 6a. Electronic structure with the ZnTe and CdTe band gaps and the common equilibrium Fermi level. The measured four defects levels are located in the CdTe band gap below Fermi level in the region from 0 down to 70meV. The states can be correlated to the interaction of minority free carriers and correlated defect states [3].

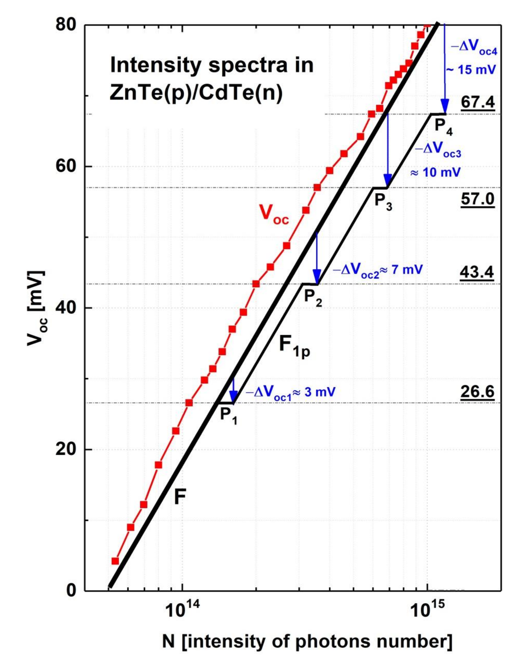

Fig. 6b. Comparison of measured Voc illumination intensity dependence (red) and correlated to it model of F_{1p}(black). The steps occurs as results of exchange interaction of defect states with free carriers in the region of coincidence with quasi Fermi level F_{1p} position.

Summary and Literature

- The increase of the number of illuminating photons leads to shift of the quasi Fermi level through the forbidden band gap region. The change of the quasi Fermi level energy contributes to the value of the generated open circuit voltage of photo junction.
- The change of quasi Fermi level energy F_{1p} of minority holes and F_{2n} of minority electrons gave the main contribution to the generated voltage of photo junction.
- The electronic defects present in the region of photo junction can be charged under illumination and can lead to the exchange interaction with free correlated minority carriers lowering or increasing their density and creating correlated change of the measured V_{oc} or quasi Fermi level position.
- The experiment allows to estimate energy position of defect structure elements and sequens of the correlated similar structure defects. electronic levels of structures like extended defects, dislocations, quantum wells etc.
- The defect can be treated as e sequence of modified photo junctions interacting with correlated minority free holes in conditions of proper illumination intensity.

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