Relevance / Irrelevance of the Electric Field Concept in Quantum Solar Energy Conversion

G.H. Bauer, R. Brüggemann
Institute of Physics, Carl von Ossietzky University , D-26121 Oldenburg, F.R. Germany

The electric field concept for the discussion/explanation of fundamental processes in quantum solar energy conversion although - even nowadays - currently applied shows substantial inconsistencies with basic physics concepts; e.g. a forwardly operated diode would not even work.

Here the formal occurrence of the magnitudes conduction and valence band, E_c and E_v and their respective spatial gradients in some of the expressions for charge carrier transport will be demonstrated. These magnitudes, however, are modified/combined by even more relevant terms for transport and consequently the so-called field in terms of gradients in E_c and E_V are only abbreviations e.g. for the thermal equilibrium carrier concentration with which the steady state photogenerated excess density has to compete. In our terminology is the effect of the space charge (in thermal equilibrium as well as in a stationary state, that might be formulated in terms of quasi-Fermi-distributions) nothing but the creation of spatially dependent energy levels for electrons and holes respectively.

Exemplarily for a low mobility absorber we create an artificial p-i-n diode by extending the space charge region of a p-n-homojunction through a respective low dopand concentration for both sides across the hypothetic thickness for light absorption (fig. 1) and we the trivial case of homogeneous generation profiles, low recombination rates and - without saying explicitly - current continuity the formal contribution of the terms grad[$E_c(x)$], grad[$E_v(x)$]. As one of the résumés we state, the (only) beneficial effect of a pin diode to consist in lower defect density and according

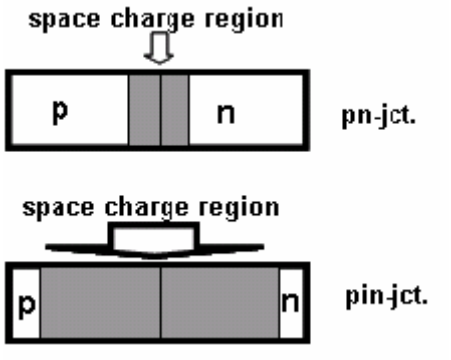

Fig. 1. Extension of a homo pn-junction towards a pin-junction by lowering the doping concentration in p- and n-type semiconductors (without modifying "substantially" the position of the Fermi-energies in the doped regimes, say, the built-in-voltage approximately identical).

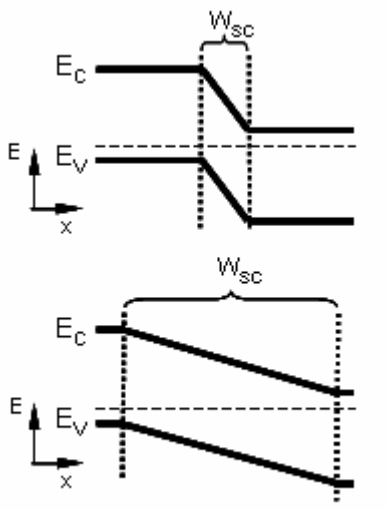

Fig. 2. Simplified band diagrams of an ideal pn-diode towards a pin-diode via the extension of the space charge regime from small compared to absorption length $W_{sc} << L_{abs} \sim 1/\alpha$ to one in the neighborhood of the absorption length $W_{sc} \approx L_{abs.}$

higher recombination life times of carriers in the i- region in comparison with n- and p-type doped regimes. An interpretation that might be consistently extended towards the “Würfel-approach” of an idealized, low/zero-defect absorber sandwiched between two membranes providing for the symmetry breaking that is necessary for the separation of excess charges.

The differential analysis for the gradient in quasi-Fermi level for electrons ε_{Fn} at position ξ in the space charge region - e.g. of a junction as well as for those in a “back-surface-field” regime - assuming the thermal equilibrium concentration as well as the excess electron density to be formulated in Boltzmann-approximation, and furthermore the generation profile to be constant (“red light”) yields for constant, means spatially independent life time τ:

$$grad(\varepsilon_{Fn}(x=\xi)) = \left(\frac{\exp[-\frac{E_C(\xi)}{kT}](g\tau)}{AkT\left(1+\frac{(g\tau)\exp[-\frac{E_C(\xi)}{kT}]}{A}\right)} \right) grad(E_C(x=\xi)) < grad(E_C(x=\xi))$$

and for spatially dependent life times, as we expect this to turn out in regimes with strong doping profile, e.g. in so-called back surface fields:

$$grad(\varepsilon_{Fn}(\xi)) = \frac{\left((\frac{1}{A})\exp[-\frac{E_C(\xi)}{kT}](g)\right)\left((\tau)grad[E_C(x=\xi)]-(kT)grad[\tau(x=\xi)]\right)}{\left(1+\frac{(g\tau)\exp[-\frac{E_C(\xi)}{kT}]}{A}\right)} < grad(E_C(\xi))$$

In conclusion we see that even in an extremely simplified approach, without spatial space charges, the so-called fields for the so-called charge separation are not identical with the driving force for carrier motion, the gradients in Fermi levels. Extrapolating our findings to band diagrams with additional spatial space charges resulting from photogeneration, locally dependent recombination and the coupling of electrons and holes for meeting current continuity, the departure of gradients in Fermi levels from gradients in conduction or valence bands gets substantially stronger.