Calibrated Room Temperature Photoluminescence for Quasi-Fermi Level Splitting and Identification of Interface Recombination in a-Si:H/c-Si-Heterojunctions

G.H. Bauer, R. Brüggemann, S. Tardon,

Institute of Physics, Carl von Ossietzky University Oldenburg, D-26111 Oldenburg, F.R. Germany

We have translated calibrated room temperature photoluminescence yields in (p)c-Si-wafers overcoated with different passivation layers, such as SiN, SiOx, (p)-, (i)-, and (n)-a-Si:H (see Fig.1) into the splitting of the quasi-Fermi levels at AM1-equivalent photon flux excitation. The departure from symmetric passivation of front and rear side, e.g. the with an (n)a-Si:H window layer and a metal at the rear, say the formation of a heterodiode has been monitored step by step via pl-yield studies (Fig. 7). Additional numerical modeling of e.g. local excess carrier densities and pl-emission (Figs.2-6) and the fit to experimental yields demonstrates the extremely high sensitivity of pl against defect densities at the hetero-interface in the regime of about (10^{10}-10^{12})cm^{-2}, as well as against the energetic position of these defects in the gap represented by a Gaussian shaped peak and with features determined by a defect pool model (Fig. 8).

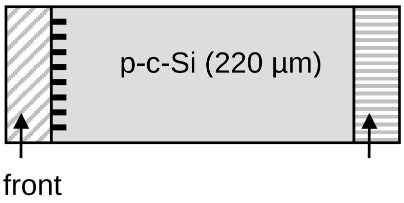


Fig. 1 Schematic geometric design of p-c-Si absorber with overcoating layers:

- SiN- or SiO_x-pssivation,
- n-, i-, or n-i-a-Si:H overcoatings,
- TCO on front and metal on rear side,
  (**-** designates interface states)

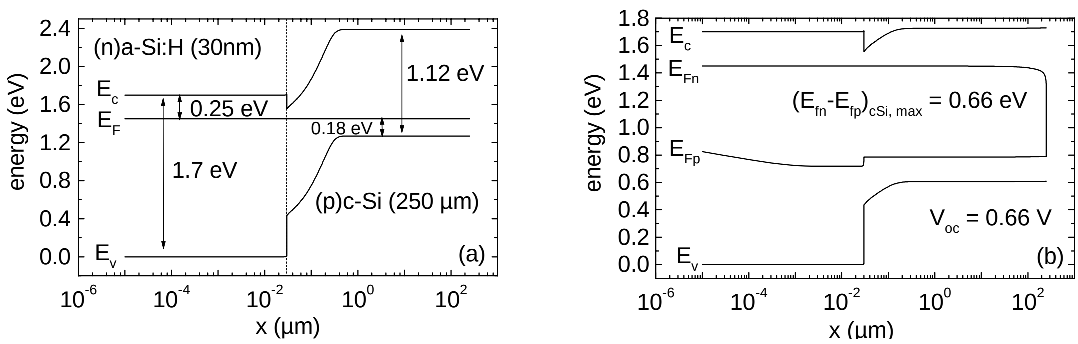


Fig. 2 Band diagram from the simulation of a (n)a-Si:H/(p)c-Si junction at thermal equilibrium (a) and at open circuit excited by a mono-chromatic photon flux of 10^{18}cm^{-2} s^{-1} at λ = 782 nm (b); for both diagrams no interface defects have been considered.

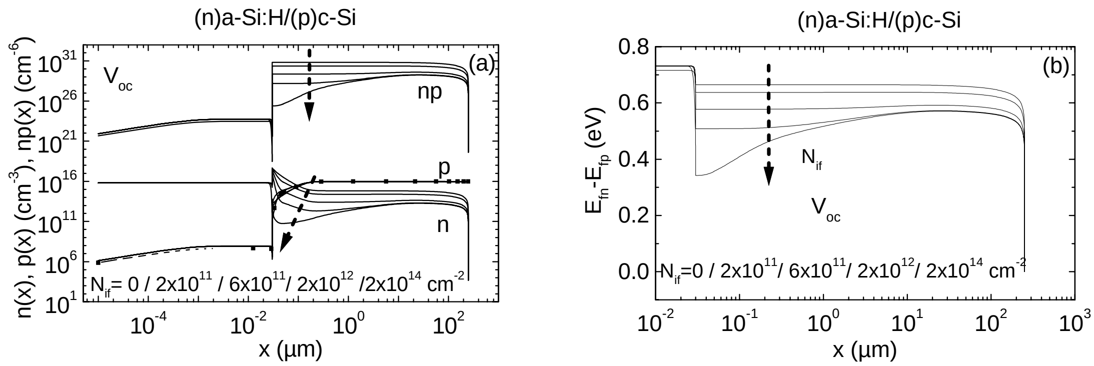


Fig. 3 Local carrier densi-ties *n(x)*, *p(x)*, and product *n(x)p(x)* (a) and splitting of quasi-Fermi levels (E_{fn}–E_{fp}) (b) for (n)a-Si:H/(p)c-Si heterodiodes for different interface defect densities N_{if} = (0, 2×10^{11}, 6×10^{11}, 2×10^{12}, 2×10^{14}) cm^{-2} in open circuit; the thickness of the interface defect layer amounts to 20 nm.

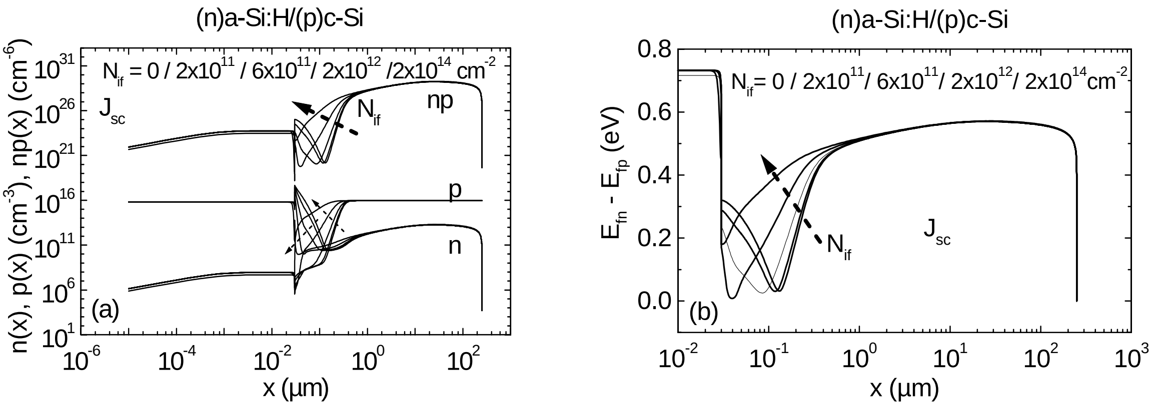


Fig. 4 Local carrier densities *n(x)*, *p(x)*, and product *n(x)p(x)* (a), and splitting of quasi-Fermi levels (E_{fn}-E_{fp}) (b) for (n)a-Si:H/ (p)c-Si heterodiodes with different interface defect densities N_{if} = (0, 2 × 10^{11}, 6 × 10^{11}, 2 × 10^{12}, 2 × 10^{14}) cm^{-2} in short circuit; thickness of the interface defect layer is 20 nm.

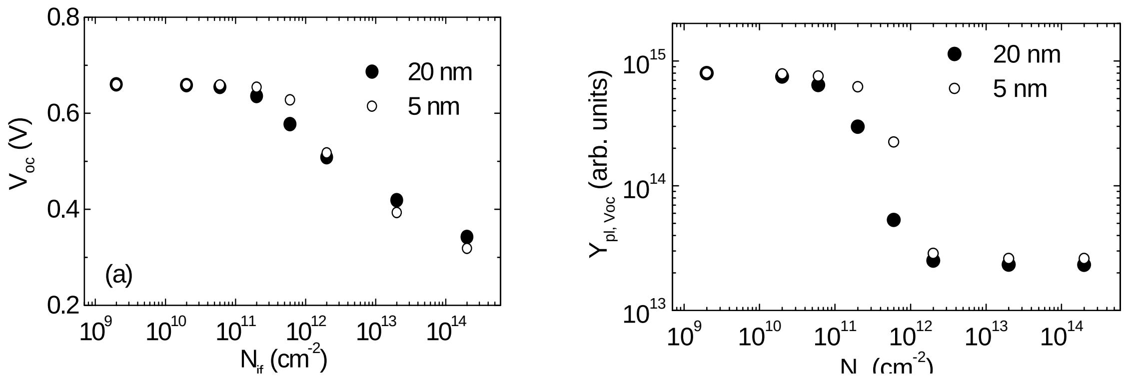
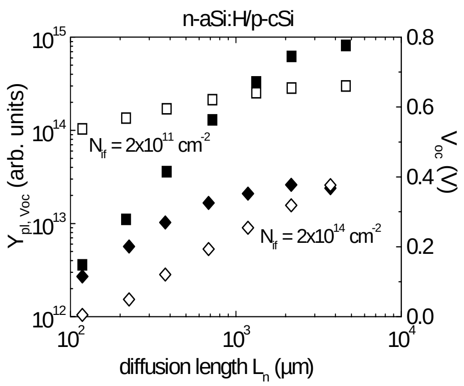
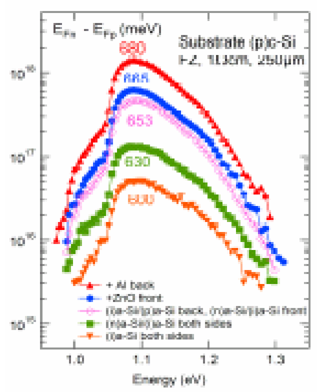


Fig. 5 Numerically calculated open circuit voltages V_{oc} (a) and luminescence photon fluxes $Y_{pl,Voc}$ (b) for a-Si:H/c-Si heterojunctions at 300K and 10^{18} cm^{-2} s^{-1} flux of monochromatic photons (λ = 782 nm) versus interface defect densities 2 × 10^{9} cm^{-2} < N_{if} < 2 × 10^{14} cm^{-2}; N_{if} distributed at the a-Si:H/c-Si interface within 20nm (closed symbols) or 5 nm (open symbols). The results for N_{if} = 2 × 10^{9} cm^{-2} are identical with those for N_{if} = 0. Note that V_{oc} drops with increasing N_{if} by about 2, whereas $Y_{pl,Voc}$ varies by a factor of 30.





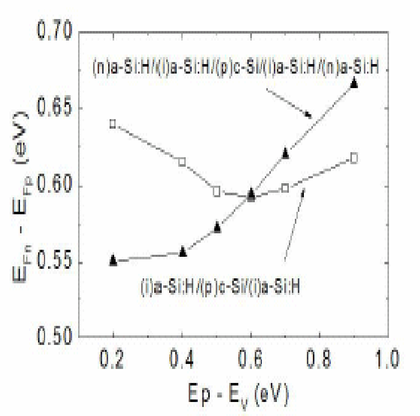


Fig. 6 Numerically calculated luminescence yields $Y_{pl,Voc}$ (closed symbols) and open circuit voltages V_{oc} (open symbols) for a-Si:H/c-Si heterojunctions at 300K and 10^{18} cm^{-2} s^{-1} flux of monochromatic photons (λ = 782 nm) versus minority diffusion lengths L_n for interface defect densities N_{if} = 2 × 10^{11} cm^{-2} (squares) and N_{if} = 2 × 10^{14} cm^{-2} (diamonds), 5 nm interface regime. Note that $Y_{pl,Voc}$ is plotted in logarithmic scale whereas V_{oc} is represented linearly.

Fig. 7 Experimental spectral 300K AM1 equivalent PL-yields of c-Si wafers overcoated with different "passivation layers

Fig. 8 Numerically simulated splitting of quasi-Fermi levels in symmetrically passivated (i)a-Si:H/c-Si/(i)a-Si:H layer structure (300K, AM1 equivalent excitation) versus energetic position of interface defect peak E_p-E_v (defect pool model) .