Effect of internal electric field in c-Si solar cells

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Abstract—**Built-in electric field of the P-N junction is expected to support the separation and enhance the collection of the charge carriers generated in solar cell absorber. If this is a case, the distribution of the electric field across the solar cell absorber should affect the device performance. Comparative modeling of P-N junction and P-i-N junction solar cells with strongly different distributions of internal electric field was carried out to reveal the performance difference. Detailed simulations show that the photovoltaic characteristics of monocrystalline silicone (c-Si) solar cells with N-type and P-i-N-type absorbers are nearly identical which indicates that the field-assisted carrier transport in the absorber layer is irrelevant to c-Si solar cell operation. Insensitivity of the device performance to the field distribution is explained by exceptionally low level of recombination loss in c-Si.**

Keywords—solar cells; carrier recombination; carrier injection; optoelectronic device modeling; numerical simulations.

I. Introduction

Typical silicon solar cell design includes moderately doped N-type or P-type absorber (base layer) separated by a narrow P-N junction from the emitter layer located immediately under the illuminated surface. Transport of optically generated carriers across the base and emitter layers is predominantly diffusive except the narrow P-N junction region where it is assisted by the electric field. P-i-N solar cell design provides for more uniform distribution of the electric field across the undoped i-type base layer and therefore should enhance the field-assisted carrier transport. Internal electric field is expected to efficiently separate the optically generated charge carriers thus decreasing the recombination losses in the solar cell absorber and ultimately improving the charge carrier collection. This very intuitive picture is however arguable [1].

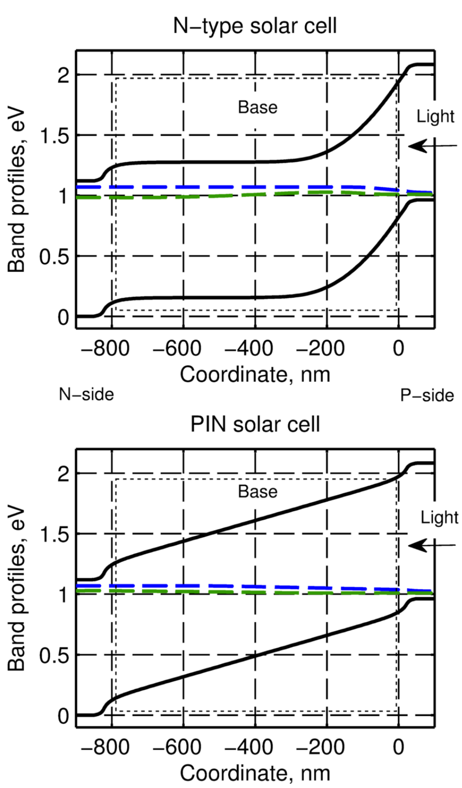

Fig.1. Band diagrams of silicon solar cell structures with N-type and PIN-type absorbers calculated at short-circuit condition. Absorber region is enclosed in the dotted box.

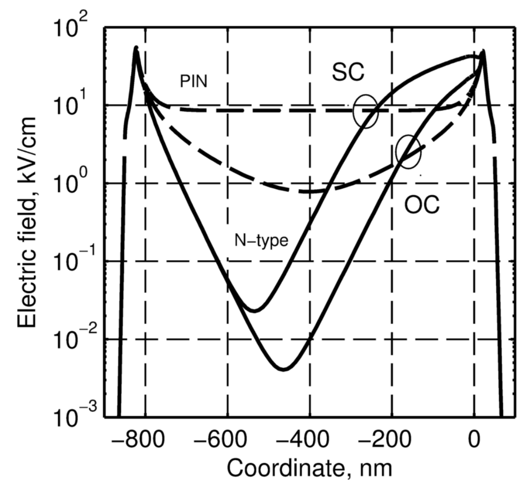

Fig. 2. Electric field distributions at short circuit (SC) and open circuit (OC) voltage. Solid lines – N-type solar cell, dashed lines – PIN-type solar cell.

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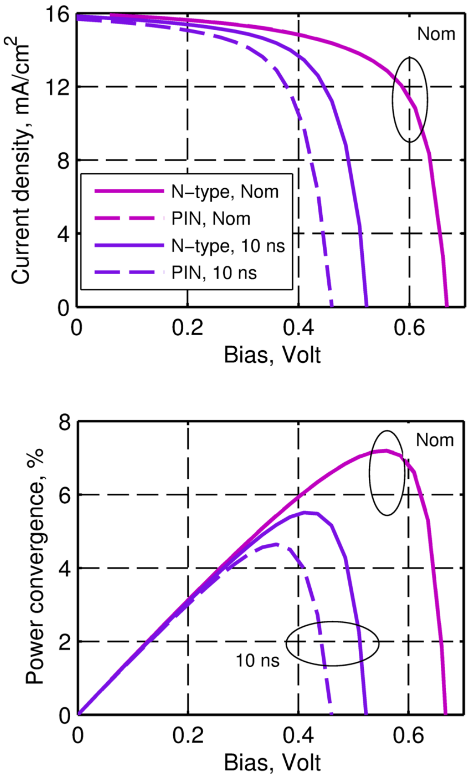

Fig. 3. Characteristics of N-type and PIN-type solar cells are indistinguishable for nominal level of c-Si recombination loss (Nom) but degrade differently in high-loss condition t_{SRH} = 10 ns.

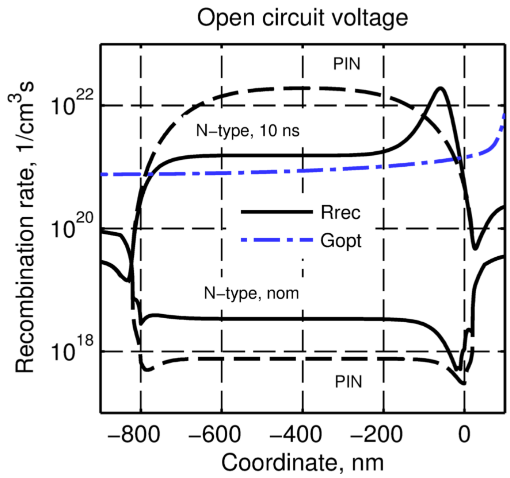

Fig. 4. Rates of optical generation (dash-dot line) and recombination loss (solid and dashed lines) at open circuit voltage calculated for nominal (c-Si) and elevated (III-V) level of Shockley-Reed-Hall recombination t_{SRH} = 10 ns.

II. Simulation Results

Figure 1 compares band diagrams of silicon solar cell structures with N-type and PIN-type absorbers calculated at short circuit condition. This example structures are used for all subsequent figures. Coordinate x=0 represents location of metallurgical P-N junction. Both structures are illuminated from the P-side with solar spectrum AM1.5 which roughly corresponds to total irradiance of 0.1 W/cm^2.

Figure 2 illustrates the distribution of internal electric field in two modeled structures at short circuit (SC) and open circuit (OC) voltage. Here and in all other figures solid lines represent N-type and dashed lines – PIN-type base structures. At both voltages, PIN-base structure demonstrates more uniform electric field distribution across the absorber layer.

Figure 3 presents photovoltaic characteristics of two modeled solar cells which have been calculated first for typical values of carrier lifetimes and mobilities accepted in c-Si [2] (two indistinguishable lines marked Nom). For both N-type and PIN-type absorbers with nominal recombination losses, these characteristics look identical which indicates that field-assisted carrier transport in base layer is irrelevant for c-Si solar cell operation [1].

Indeed, the nominal level of recombination losses in c-Si is exceptionally low, which makes the charge carrier collection insensitive to the sweeping action of the electric field in the base layer. Figure 4 compares the rates of optical generation (dash-dot) and nominal recombination loss at open circuit voltage (lower pair of lines). For such low recombination rate, the current distribution across the base layer with nominal c-Si recombination loss is determined solely by the dominant rate of optical generation and therefore is not affected by the structure design.

At higher level of Shockley-Reed-Hall recombination, e.g. typical for III-V materials, sensitivity to the electric field in the absorber is restored. In high-loss regime, photovoltaic characteristics degrade differently for structures with N-type and PIN-type absorbers (see Fig. 3). Interestingly, PIN-type solar cell reveals performance inferior to the common P-N type structure. Two upper curves in Figure 4 compare the corresponding recombination losses. Loss is notably higher in PIN structure due to excessive hole injection into the undoped base layer.

For solar cell modeling we use COMSOL-based simulation package developed at Ostendo Technologies Inc. [3].

References

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