Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 55 (2014) 71 – 76

Energy Procedia

4th International Conference on Silicon Photovoltaics, SiliconPV 2014

A distributed electrical model for interdigitated back contact silicon solar cells

Daniele Giaffreda[a], Maarten Debucquoy[b], Paolo Magnone[a,*], Niels Posthuma[b], Claudio Fiegna[a]

[a] ARCES, University of Bologna, Via Venezia 260, I-47521, Cesena, Italy
[b] IMEC, Kapeldreef 75, B-3001, Heverlee, Belgium

Abstract

In this paper we introduce a quasi 3-D electrical model for a high efficiency interdigitated back contact (IBC) solar cell. This distributed electrical network is based on two-diodes circuit elementary units. It allows accounting for the resistive losses due to the transport through the emitter, the back surface field (BSF) and the fingers and busbars metallization. Moreover, it can model the electrical shading losses attributed to the BSF busbar. We calibrated the electrical components of the model according to experimental measurements on real devices. The validity of the model is demonstrated by the good agreement between simulation and experimental results for dark and illuminated IV measurements with and without masked busbars. The model can now easily be applied to simulate and optimize different metal grid layouts.

Peer-review under responsibility of the scientific committee of the SiliconPV 2014 conference

Keywords: IBC; back contact; back junction; electrical modeling; solar cell; SPICE

1. Introduction

Interdigitated Back-Contact IBC solar cells represent a solution to improve the conversion efficiency (above 24%), due to the absence of a front metallization grid [1, 2]. However, there are also some challenges related to the

* Corresponding author. Tel.: +39 0547 339539
E-mail address: paolo.magnone@unibo.it

Peer-review under responsibility of the scientific committee of the SiliconPV 2014 conference
doi:10.1016/j.egypro.2014.08.079

design of an IBC solar cell, one of them being the electrical shading effect [3]. In order to reach the best cell design, a modelling environment is essential in the photovoltaic research field.

Several activities are presented in literature about the TCAD device modelling of IBC solar cells, which report important analyses regarding doping profiles and recombination mechanisms [3, 4]. However, due to the large computational effort required for this type of device analysis, the simulation domain must be limited to a small symmetry element of the cell. Consequently, simulation and optimization of metal grid patterns, including fingers and busbars, is not straightforward. In the case of large area IBC solar cells, a proper modeling of resistive losses and electrical shading effect, due to the fingers and the busbars and leading to a reduction of both Fill Factor (FF) short-circuit current (J_{sc}), is fundamental in order to optimize the metal grid design and to achieve a large conversion efficiency (η).

A distributed modelling approach like the activities presented in [5, 6] can allow reducing the computational effort compared to the TCAD device simulation and at the same time can give an accurate description of large area solar cells. The purpose of this paper is to introduce a quasi 3-D distributed electrical model for IBC solar cells, which takes into account the series resistance components as well as the recombination losses. The tool is able to simulate the whole solar cell in a reduced computational time. Moreover, the model allows accounting for different illumination conditions and geometrical configurations of the rear grid (number of fingers, geometry and number of busbars). BSF and emitter busbar areas are also included in the distributed network, hence accounting for FF losses and electrical shading effects.

The reminder of the paper is organized as follows: in section 2 we report the details of the distributed electrical network; in section 3 we describe the methodology adopted for the calibration and the validation of the distributed tool; finally, in section 4, we summarize the main achievements of the work.

2. Distributed model of an IBC solar cell

In most back-junction solar cell structures as well as the one shown in Fig. 1a and Fig. 1b, the emitter, the BSF region and the metallization fingers are designed in an interdigitated pattern. In particular, both emitter and n^+ BSF diffusions are placed on the rear side, possibly with a narrow non-diffused gap region in between. As reported in Fig. 1a, we can identify three different regions in the IBC cell: finger region, emitter busbar and BSF busbar. Hence, in order to properly model the electric behavior of a complete IBC solar cell, we need to consider different elementary units for the three above-mentioned regions. The electrical models of the three elementary units are reported in Fig. 2a, 2b and 2c.

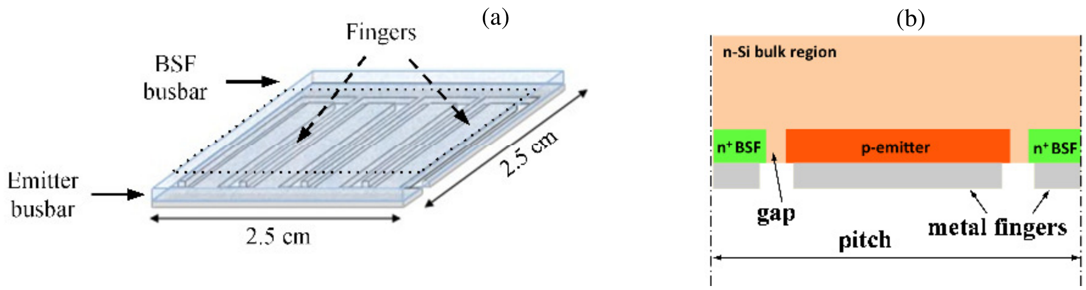

Fig .1. a) Simplified drawing of the considered IBC cell structure. b) Schematic cross section of the 2-D symmetry element of an IBC cell. The pitch is the sum of emitter, n^+BSF and gap width.

Each unit is basically composed by two diodes accounting for the recombination mechanisms of the p-n junction, a shunt resistance R'_{SH}, a current source (I_{PH}) proportional to the solar irradiation G (W/m^2) and a network of resistances modeling the distributed resistive effects. The contact resistances of fingers are modelled with the R_{CE} and R_{CBSF}, while R_{ME}, R_{MBSF}, R_{MEBB} and R_{MBSFBB} represent the distributed resistance due to the conduction through the metal structures (i.e. fingers and busbars). Finally, each elementary unit presents an equivalent resistances (R_E) to account for the transport through the emitter region as well as an equivalent resistances (R_{BSF}) to account for the transport through the BSF region. The electrical components are calculated according to the area of the elementary unit and its physical structure. The relatively longer path in the BSF region (typically in the order 1-2 mm) leads a reduction of the minority carrier collection probability. Therefore, in the case of Fig. 3c, i.e. BSF busbar region, the current source is calculated as:

$$I_{PH\_BSF}(i,j) = A_U(i,j) \cdot J_{PH0}(i,j) \cdot \alpha \cdot \left(1 - e^{-\frac{1}{\alpha}}\right) \tag{1}$$

being A_U the area of the elementary unit, J_{PH0} the photogenerated current density in the finger region, and $\alpha = D_{length} / W_{BSFBB}$ the ratio between the bulk diffusion length and BSF busbar width. Eq. (1) allows accounting for the reduction of short-circuit current due to the shading effect.

The whole solar cell can be modelled by opportunely interconnecting these elementary units. The proposed distributed network can be used to model the behavior of the solar cell in both dark and illuminated conditions. In particularly, the dark analysis can be easily performed by forcing $I_{PH} = 0$. Moreover, the illumination conditions can be selectively defined for the different regions; hence, the busbars can also be considered shaded when analyzing the illuminated cell.

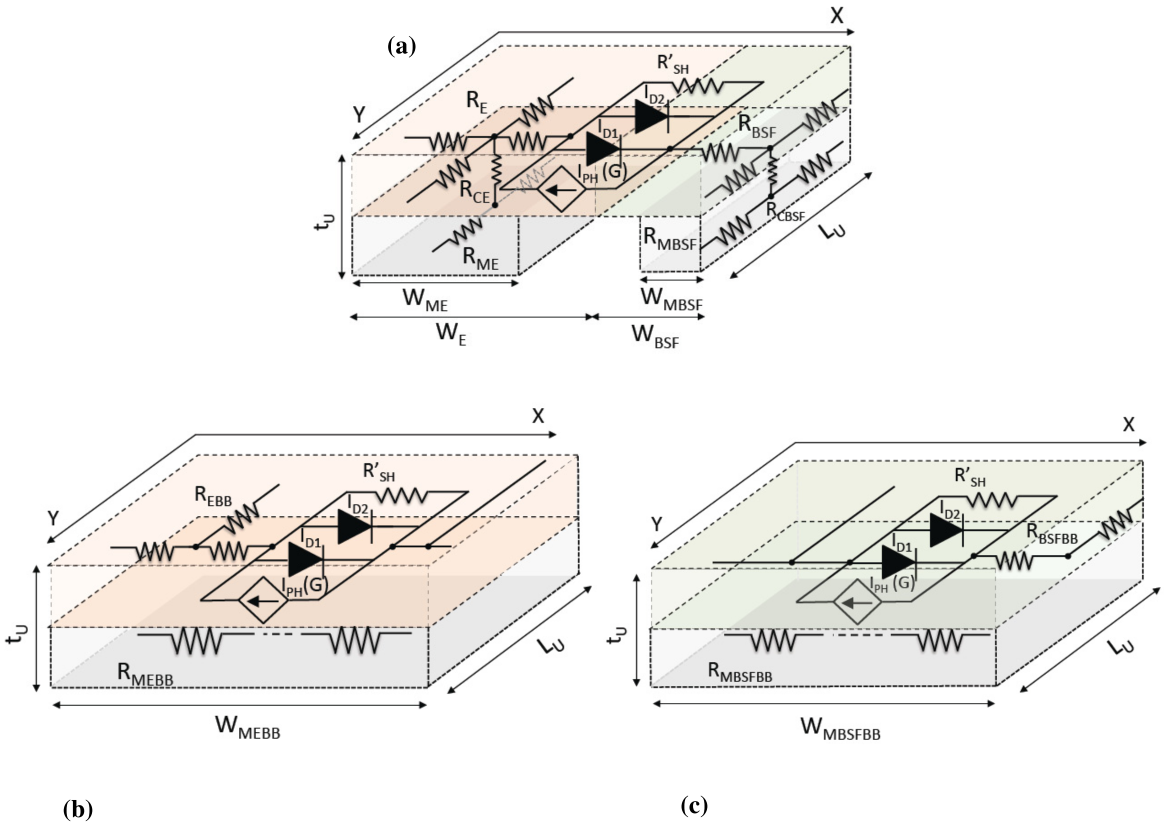

Fig. 2. a) Elementary unit for the interdigitated region, representing a region equal to a half pitch distance (see Fig. 1). b) Elementary unit for the emitter busbar region. c) Elementary unit for the BSF busbar region.

3. Model calibration and validation

In order to calibrate the developed model we investigated representative samples of n-type IBC silicon solar cells with a 2.5x2.5 cm^2 area and two busbars [7]. The values of the series resistances in the model were calculated based on the measured physical properties of the cell (see Table 1). The values for the diodes parameters and the shunt resistance were obtained from dark IV measurements. Then, through the illuminated IV curves, the equivalent current generators I_{PH} (i,j) have been calibrated. In order to isolate the impact due to the busbars area on the solar cell performance, we carried out illuminated IV measurements using different masks. These masks allowed to illuminate only the interdigitated region of the cell, the interdigitated region and one of the busbars or the interdigitated region and both busbars. The comparison between experimental measurements and simulation results are reported in Fig. 3, Fig. 4 and Table 2.

Due to the large width of the BSF busbar, the local J_{PH} in this region is reduced by the electrical shading effect. This is illustrated in Fig. 4 where a comparison is made between the illuminated JV of the cell with the emitter busbar region obscured and with both the busbar regions obscured. In fact, as reported in Table 3, a J_{sc} of 39.3 mA/cm^2 has been extracted for the first case, while a J_{sc} of 41.67 mA/cm^2 has been calculated when only the finger region, excluding the busbars, has been illuminated. On the other hand, when the emitter busbar region is illuminated, a significant reduction of FF, of 3.2%$_{abs}$, has been simulated. As can be seen, there is a good match between experimental and simulation results.

Table 1. Physical and electrical properties of the considered IBC silicon solar cells used for the distributed electrical model.

Parameter	Value	Description
ρ_{Em} (Ω/☐)	80	*Emitter sheet resistance*
ρ_{BSF} (Ω/☐)	50	*BSF sheet resistance*
ρ_{bulk} (Ω/☐)	120	*Bulk sheet resistance*
ρ_M ($\Omega\cdot cm$)	$2.7\cdot10^{-6}$	*Resistivity of metallization*
ρ_C ($\Omega\cdot cm^2$)	$1\cdot10^{-4}$	*Specific contact resistance*
t_M (μm)	2	*Metal thickness*
W_{BB} (μm)	1900	*Busbar width*

Table 2. Comparison between experimental and simulate efficiency.

	Model	**Experimental**
w/o Busbars	23.29 %	23.15 %
with BSF BB	21.90 %	21.89 %
with Emitter BB	22.38 %	22.43 %

Table 3. Figures of merit in the case of the simulated IBC solar cell.

	w/o Busbars	**with BSF busbar**	**with Emitter busbar**
J_{sc} (mA/cm^2)	41.67	39.32	41.67
V_{oc} (mV)	691.1	691.1	691.1
FF (%)	80.89	80.67	77.71
η (%)	23.29	21.90	22.38

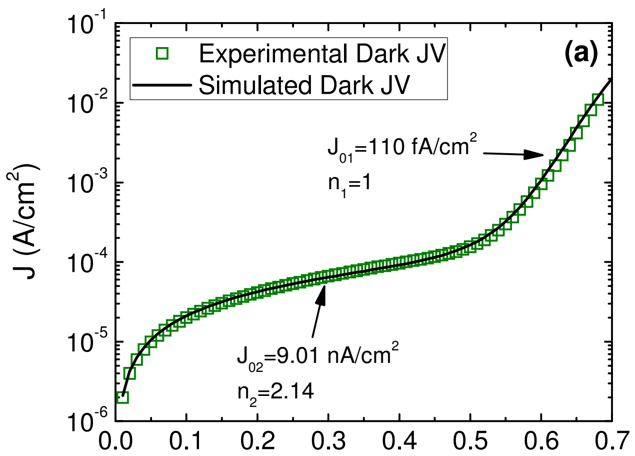

Fig. 3. Experimental and simulated dark JV curves referred to the whole IBC cell.

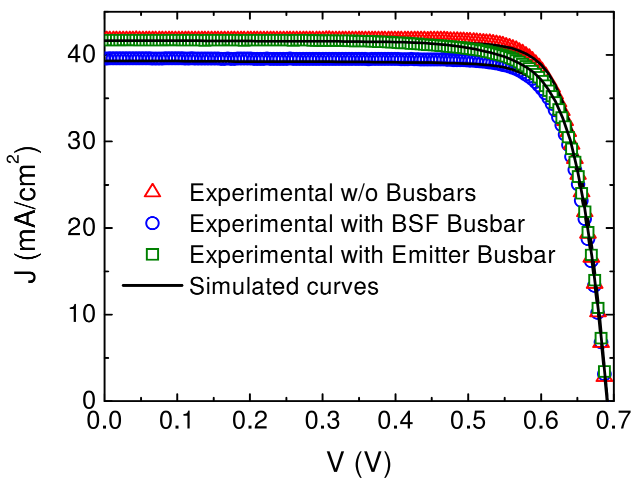

Fig. 4. Experimental and simulated illuminated JV curves.

4. Conclusions

In this paper, we presented a distributed electrical network able to model a complete IBC silicon solar cell. The model gives an accurate electrical description of the solar cell and allows to separately analyzing the electrical shading and FF losses due to the busbars regions with respect to the remaining part of the solar cell. We calibrated the developed model by means of experimental measurements. The simulation results are in good agreement with experimental curves. We observed that, due to the large busbars width, both simulation results and experimental measurements confirm a reduction in J_{sc} due to the electrical shading and a FF degradation mainly ascribed to the emitter busbar. By means of this model, different metal grid layouts for large area cells can now be simulated and optimized.

References

[1] P. J. Cousins, D. D. Smith, L. Hsin-Chiao, J. Manning, T. D. Dennis, A. Waldhauer, K. E. Wilson, G. Harley, W. P. Mulligan. Generation 3: Improved performance at lower cost. *Proc. 35th IEEE Photovoltaic Specialist Conference PVSC*, Honolulu, Hawaii, USA, 2010, pp. 275-278.

[2] M. Aleman, J. Das, T. Janssens, B. Pawlak, N. Posthuma, J. Robbelein, S. Singh, K. Baert, J. Poortmans, J. Fernandez, K. Yoshikawa, P. J. Verlinden. Development and Integration of a High Efficiency Baseline Leading to 23% IBC Cells. *Energy Procedia*, 2012, vol. 27, pp. 638-645.

[3] C. Reichel, F. Granek, M. Hermle, S. W. Glunz. Investigation of electrical shading effects in back-contacted back-junction silicon solar cells using the two-dimensional charge collection probability and the reciprocity theorem. *J. Appl. Phys.*, 2011, vol. 109.

[4] M. Hermle, F. Granek, O. Schultz-Wittmann, S.W. Glunz. Shading effects in Back-Junction Back-contacted silicon solar cells. *Proc. 33rd IEEE Photovoltaic Specialist Conference PVSC*, St. Diego, CA, USA, 2008.

[5] D. Giaffreda, P. Magnone, M. Meneghini, M. Barbato, G. Meneghesso, E. Zanoni, E. Sangiorgi, C. Fiegna. Local Shunting in multicrystalline silicon solar cells: distributed electrical simulations and experiments. *IEEE J. Photovoltaics*, 2014, vol. 4, no. 1, pp. 40-47.

[6] F. Haase, S. Eidelloth, R. Horbelt, K. Bothe, E. Garralaga Rojas, and R. Brendel. Loss analysis of back-contact back-junction thin-film monocrystalline silicon solar cell. *Proc. 37th IEEE Photovoltaic Specialist Conference PVSC*, Seattle, USA, 2011, pp. 2874-2877.

[7] B. J. O'Sullivan, M. Debucquoy, S. Singh, A. Uruena De Castro, M. Recaman Payo, N. E. Posthuma, I. Gordon, J. Szlufcik, J. Poortmans. Process Simplification for High Efficiency, Small Area Interdigitated Back Contact Silicon Solar Cells. *28th European Photovoltaic Solar Energy Conference*, Paris, France, 2013, pp. 956-960.