Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 55 (2014) 11 – 16

Energy Procedia

4th International Conference on Silicon Photovoltaics, SiliconPV 2014

Conceptual comparison between standard Si solar cells and back contacted cells

Adnan Ali[a], Tobias Ohrdes[b], Hannes Wagner[c], Pietro P. Altermatt[c,] *

[a]*Department of Physics, Government College University Faisalabad, Faisalabad, 38000, Pakistan*
[b]*Institute of Solar Energy Research (ISFH), Hamelin, Am Ohrberg 1, 31860, Germany*
[c]*Leibniz University of Hannover, Department of Solar Energy Research, Institure of Solid-State Physics, Appelstr. 2, 30167, Hannover, Germany*

Abstract

It is often stated that one of the main advantages of back-contacted (BC) Si solar cells over standard cells is that shading due to the front-finger metallization is avoided – while it is also often stated that BC cells are prone to "electronic shadowing", which means that the carrier collection efficiency in front of the back-surface-field (BSF) may be reduced. We compare these two cell concepts in two ways: by means of an extensive collection of measured IV data from literature, and by interpreting as well as quantifying the differences with the aid of numerical device simulation. Both literature data and simulations indicate that BC cells have a J_{sc}-advantage of maximally about 1 mA/cm^2, but in V_{oc} and FF there is no clear advantage or disadvantage over standard cells. With a parameter study, we reveal the main design advantages and weaknesses in each cell type. Our numerical device modeling indicates that one of the most crucial design advantages of BC over standard cells is that the collection of minority carriers in the emitter is rather unimportant, which leaves greater flexibility in emitter design than in standard cells.

Keywords: IBC; Back surface field; Cz; short ciruict current density

---

1. Introduction

The market share of back-contacted (BC) Si solar cells in the crystalline Si cells market is presently near 3% and is forecast to grow to near a quarter in ten years [0F1]. While the main driver for the market share may be

---

* Corresponding author. Tel.: +49-511-762-5505.
E-mail address: altermatt@solar.uni-hannover.de

doi:10.1016/j.egypro.2014.08.003

technological aspects, especially in module fabrication, this paper addresses issues on a pure device design level by sophisticated numerical device modeling. We follow questions like: is the BC cell type inherently better than the standard cell? If so, what specifically is better and by how much? Where are design advantages and weaknesses in each cell type? For exploring these questions, we optimize a standard cell and a BC cell separately, so the strength of each cell type comes out individually. From these two optimized cell structures, we vary some important device parameters to reveal the dynamics of cell behavior in non-optimized conditions of mass fabrication.

2. Experimental data from literature

Fig. 1 shows experimental IV parameters reported mainly during the past few years in various journals and the main PV conferences. We restrict ourselves to front-junction/front-back contacted cells, made of the materials as indicated, and to rear-junction/rear-contacted cells, mostly made of Cz n-type wafers. There is some uncertainty in the BC data because the IV parameters of BC cells are still sometimes given for "effective" aperture, and rather often it is not clearly stated how the cell was contacted and illuminated during measurements. This casts some doubt on whether the absence of a front metallization technology really is a clear advantage over standard cells. When interpreting Fig. 1, we emphasize on the upper margins of the data clouds. There is a clear tendency that J_{sc} of BC cells, are about 1mA/cm^2 higher than in standard cells, but only at cell efficiencies below 21 %. At higher efficiency levels, the differences diminish because advanced light trapping schemes are applied in standard cell structures (mostly PERL). Because BC cells would benefit from such schemes, too, we conclude that there is indeed a clear J_{sc}-advantage of BC cells over standard cells, as is commonly claimed. Note that the efficiencies above about 20% are accomplished with either p-type FZ material or n-type material only.

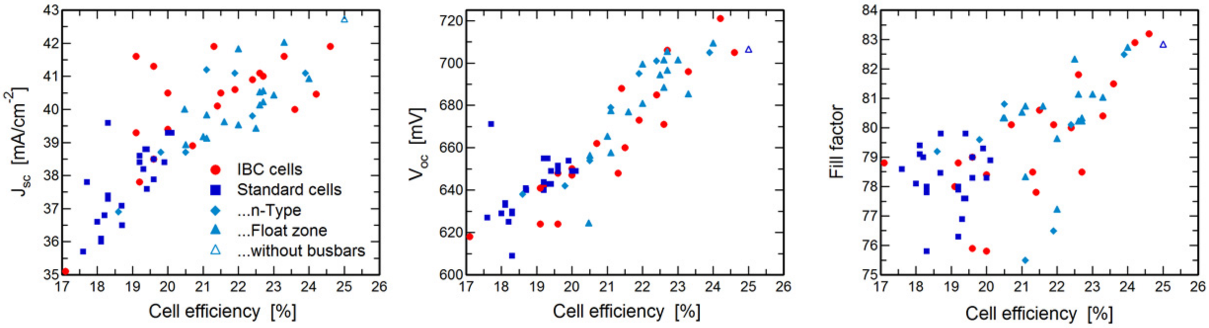

Fig. 1. A collection of experimental data from various journals and from the main PV conferences during the past few years. J_{sc}, V_{oc} and FF values are taken solely from front-junction/front-back contacted cells (blue symbols) and rear-junction/rear-contacted cells (red symbols) and plotted versus efficiency.

In contrast to J_{sc}, both V_{oc} and FF data clouds have very similar upper margins in both cell concepts. The FF data show considerable scattering because various phenomena diminish FF: resistive losses, injection-dependent lifetimes (particularly in p-type Cz material), "dark-diode"-regions in BC cells with non-optimised bus bars, etc. However, the highest FF levels seems to be mostly reached by both cell concepts at all efficiency levels.

The fact that V_{oc} is rather the same in both cell concepts is somehow surprising. The emitter in standard cells must conduct all majority carriers laterally plus about a third of all minority carriers vertically, so it must be designed with two strongly opposing tendencies between (i) metal shading and minority carrier collection and (ii) resistive losses, which clearly compromises the emitter saturation current J_{0e} and with this also V_{oc}. Therefore, the V_{oc} graph may be seen as an indication that the front surface field (FSF) of BC cells is not sufficiently well designed nor fully understood.

The fact that FF is rather the same in both cell concepts is also somehow surprising. BC cell designers tend to claim that having all metallization at the rear gives more freedom to reach lower series resistance losses. Is this freedom sufficiently exploited? Or are there other effects that compensate FF?

3. Numerical device modelling

To interpret the above results, two-dimensional numerical device modelling is performed with SENTAURUS [2], applying up-to-date physical models for silicon [3,4] and the Al-alloyed BSF [5,6]. A comparison between the two cell concepts can only be consistent if a passivation scheme is chosen that is applicable to both n- and p-type material. We choose a thin thermal SiO_2 layer, capped with PE-CVD SiN_x, which has rather equal passivation properties to alnealed SiO_2. While experimental data and models for this type of passivation exist at high doping concentrations [7,8], we had to collect published experimental data at low dopant concentrations [9] and parameterize our own model, as shown in Fig. 2(a). The differences between standard thermal SiO_2 (solid lines) and alnealed SiO_2 (dashed lines) is rather consistent for the wafer resistivities of 0.5, 0.7 and 1.5 Ωcm.

The optical generation was modelled with the raytracer SUNRAYS [10]. As we choose the PERL/PERC structure for standard cells as shown in Fig. 2(b), it is realistic to assume the same optical generation profile in both BC cells and standard cells (apart from the shading losses).

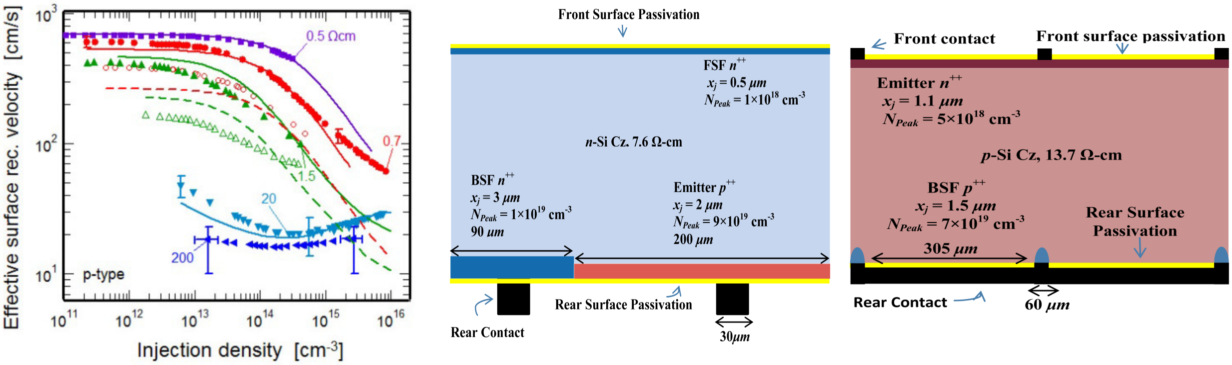

Fig. 2. (a) effective surface recombination velocities (symbols) and our empirical model (lines) of thermal SiO_2 passivation on wafers with the indicated resistivcity. Empty symbols and dashed lines indicate the improvement due to Alneal, which is similar to SiO_2/SiN_x stacks. (b) optimised back contact and PERL/PERC cells.

Both cell concepts are optimized by simulating a design-of-experiments (DOE) iteratively as described in Ref. [11]. Finding an optimum design requires that the efficiency has a maximum somewhere in the parameter space of the DOE, we fix the width of the metal contacts. Also note that a DOE approach optimizes only the parameters that affect the dominating losses. For example, the optimum junction depth of the BSF in the standard cell would be deeper, but due to the chosen passivation, a deeper BSF does not increase cell efficiency considerably. Our DOE modeling indicates that one of the most crucial design advantages of BC over standard cells is that the collection of minority carriers in the emitter is rather unimportant, which leaves greater flexibility in emitter design than in standard cells. The optimum device parameters, indicated in Fig. 2(b), are not necessarily realistic for mass production, but they allow us to quantify the potentially possible IV parameters.

Since we optimised most features in both cell concepts separately, our comparison is as unbiased as possible. Still, it is a difficult task to compare two different cell concepts without biasing any advantage or disadvantage in one or the other cell concept. For example, we compare the two cell concepts in the module, not in air, because about 50% of the light impinging on the front metal is reflected back to the cell via the module glass [12], while in air, most of it would be lost to space.

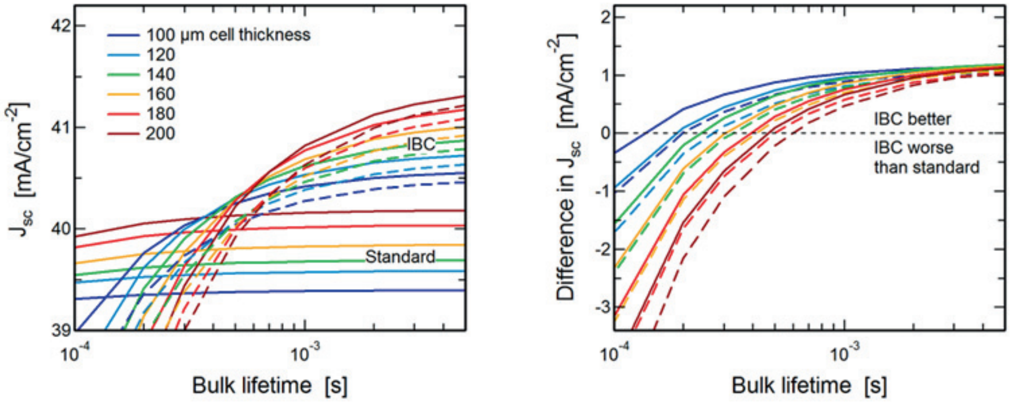

Fig. 3. (a) Simulated J_{sc} in dependence of the bulk SRH lifetime for the two optimised cells of Fig. 2(b), for various cell thicknesses; (b) shows the differences. The dashed lines indicate an I BC cell with 180 µm wide BSF (instead of 90 µm).

Fig. 3(a) shows the simulated J_{sc} in dependence of bulk SRH lifetime τ. J_{sc} of interdigitated back contact (IBC) cells is about 1 mA/cm^2 lager than in the standard cells, for τ in the millisecond range. In air, this difference increases to about 2 mA/cm^2, as indicated for example in Ref. [13]. If alternative front metallization schemes are applied, such as the multi-wire approach, the difference decreases by a further 0.14 mA/cm^2 [14] or even further if the front metal fingers are made thinner than presently technologically feasible with screen-printing. If the BSF of the IBC cell is made 180 µm wide, which is more realistic, J_{sc} decreases only slightly for τ in the millisecond range, see the dashed lines in Figs. 3. By the way, the simulated V_{oc} turns out to be very similar in both cells concepts: for τ > 1 ms, V_{oc} saturates near 680 mV (it would reach higher values if the DOE included the width of the metal contacts, a different emitter structure in the standard cell, and non-diffused, very well passivated surfaces in the BC cell).

4. Implications

From the literature data and our simulations we conclude that – in terms of measured IV parameters – BC cells have a clear J_{sc}-advantage of maximally about 1 mA/cm^2, with advanced front metallization even less, and in V_{oc} and *FF* there is no clear advantage or disadvantage over standard cells. Hence, whether this J_{sc}-advantage alone will lead to a considerably larger market share of BC cells in the near future [1] probably depends on technological and economical aspects rather than on pure cell design criteria.

So we return to the question in the introduction: where are design advantages and weaknesses in each cell type? BC cells tend to require more processing steps than standard cells due to the higher structuring of the rear surface. To come out of a niche market and compete with standard cells, it may be advantageous to avoid non-diffused surface areas at the rear, and to keep the emitter area at 50%. We changed the above optimized structure to 50% emitter coverage and depict the simulation results for 160 µm cell thickness in Fig. 4(a), and in Fig. 4(b) the minimal pitch required to have an J_{sc}-advantage over the standard cells. At these minimal pitches, V_{oc} and cell efficiency of both cell types are similar.

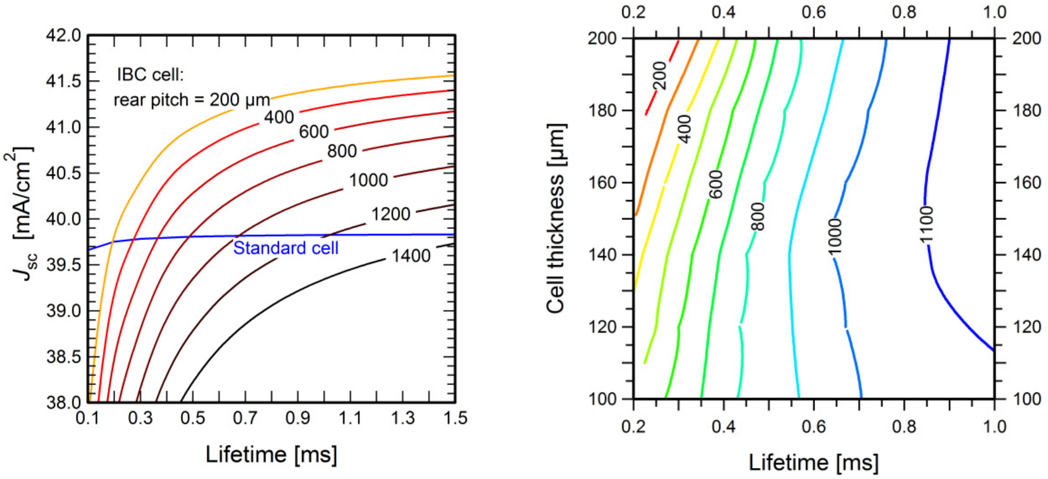

Fig. 4. Simulation of IBC cells with 50% emitter coverage. (a) Comparison of J_{sc} with a standard cell, simulated with 160 µm thickness; (b) the minimally required rear pitch so the IBC cell has a higher J_{sc} than the standard cell.

From the other view point, if one likes to stay with the standard design but compete with BC design, the following research areas may be decisive: (i) one needs not only to improve the front metallisation (in terms of shading reduction while keeping a low series resistance), but also to improve the light trapping scheme. A possibility is inverted pyramids, for example fabricated by ablating holes in a KOH-protective layer with a laser prior to KOH etching. (ii) In Fig. 1, higher cell efficiency than about 20% was obtained only with either FZ or n-type materials. Therefore, it is crucial for standard cells to develop p-type wafer material that has similarly high excess carrier lifetimes as n-type wafers, for example by the deactivation of the B-O complex, or by challenging the Ga-doping patent with the help of historical papers about Ga-doping. Or another possibility is to switch standard cells to n-type Cz wafers. However, this poses challenges on p-type emitters, and one needs to be aware that one of the biggest advantages in BC cell design is that the boron-doped emitter does not need to transport minority carriers and therefore can be compromised by technological restrictions.

References

[1] International Technology Roadmap for Photovoltaic (ITRPV), 2013 Results, March 2014, available at www.itrpv.net.
[2] Sentaurus Device manual, Synopsys Inc., Mountain View, CA, 2013.
[3] Altermatt PP. Models for numerical device simulations of crystalline silicon solar cells—a review. J Comput Electron 2011;10:314–30.
[4] Richter A, Glunz SW, Werner F, Schmidt J, Cuevas A. Improved quantitative description of Auger recombination in crystalline silicon. Phys Rev B 2012;86:165202–15.
[5] Rüdiger M, Rauer M, Schmiga C, Hermle M. Effect of incomplete ionization for the description of highly aluminum-doped silicon. J Appl Phys 2011;110:024508–14.
[6] Rosenits P, Roth T, Glunz SW. Erratum on determining the defect parameters of the deep aluminum-related defect center in silicon. Appl Phys Lett 2011;99:239904–04.
[7] Altermatt PP, Schumacher J O, Cuevas A, Kerr MJ, Glunz SW, King RR, Heiser G, Schenk A. Numerical modeling of highly doped Si:P emitters based on Fermi–Dirac statistics and self-consistent material parameters. J Appl Phys 2002;92:3187–97.
[8] Altermatt PP, Plagwitz H, Bock R, Schmidt J, Brendel R, Kerr MJ, Cuevas A. The surface recombination velocity at boron-doped emitters: comparison between various passivation techniques. 21st EU PVSEC, Dresden, 2006, p. 647–50.
[9] Data measured at the Institute for Solar Energy Research Hamelin (ISFH), Germany, and published mainly in various PhD theses over the years.
[10] Brendel R. SUNRAYS: A versatile ray tracing program for the photovoltaic community. Proc. 12th EU PVSEC, Amsterdam, 1994, p. 1339–42.

[11] Müller M, Altermatt P P, Wagner H, Fischer G. Sensitivity Analysis of Industrial Multicrystalline PERC Silicon Solar Cells by Means of 3-D Device Simulation and Metamodeling. IEEE, J Photovoltaics 2014;4:107–13.

[12] Woehl R, Hörteis M, Glunz SW. Determination of the effective optical width of screen-printed and aerosol-printed and plated fingers. 23rd EU PVSEC, Valencia, 2008, p. 1377–80.

[13] Rüdiger M, Steinkemper H, Hermle M, Glunz SW. Numerical Current Density Loss Analysis of Industrially Relevant Crystalline Silicon Solar Cell Concepts. IEEE, J Photovoltaics 2014;4: 533–39.

[14] Braun S, Hahn G, Nissler R, Pönisch C, Habermann D. Multi-busbar solar cells and modules: high efficiencies and low silver consumption. Energy Procedia 2013;38:334–39.