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Approach for a simplified fabrication process for IBC-SHJ solar cells with high fill factors

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Abstract

In this paper, interdigitated back contacted silicon heterojunction (IBC-SHJ) solar cell results as well as two dimensional device simulations are presented. The simulation indicates that for the minority contact (emitter) the coverage of the metallisation should be nearly 100 %, while this is less critical for the majority contact (BSF). We present experimental results for an IBC-SHJ solar cell with a metallisation fraction of 100 % for the emitter and approximately 65 % for the BSF, with a high fill factor of 77.7 % and an independently confirmed energy conversion efficiency of 19.4 %.

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Keywords: back contacted; silicon heterojunction; simulation; contact separation

1. Introduction

The combination of back-contacting schemes (high short-circuit current density (j_{SC}) potential [1]) with amorphous/crystalline silicon (a-Si:H/c-Si) heterojunctions (SHJ) (open-circuit voltage (V_{OC}) of 745 mV shown by Kinoshita *et al.* [2]) offers very high effciency potential. There has been a growing activity concerning research in the field of back-contacted back silicon heterojunction (BCB-SHJ) solar cells over the last years, since Lu *et al.* presented the first BCB-SHJ solar cell based on an n-type silicon absorber [3], using an interdigitated back-contact scheme (IBC-SHJ). Meanwhile, many groups are working in the field of back contacted SHJ solar cells. However, structuring the back side for IBC-SHJ is usually rather complex. In particular, the separation of the emitter from the BSF region has to be well done to ensure high fill factors [4, 5]. To ensure good separation of the two contacts, we [6] and others [7] are using insulating layers, e.g. SiN_x/SiO_2 as gap passivation layer between emitter and BSF. However, this requires another layer at the back side and hence increases process complexity. On the other hand, omitting an insulating layer implies that either the emitter or the BSF cannot be fully metallised to avoid shunting.

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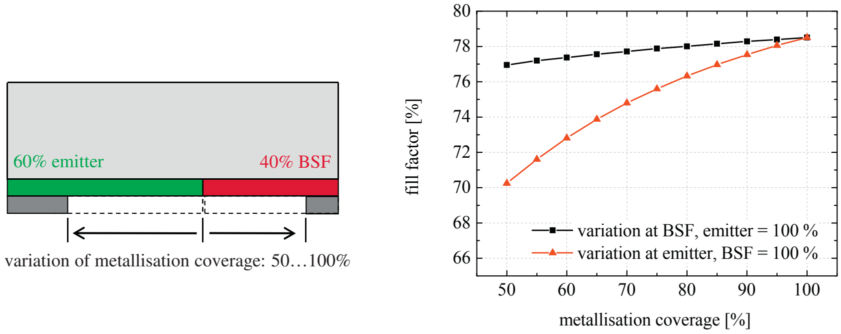


Fig. 1. Left: Schematic sketch of the simulated symmetric element. Right: Fill factor as a function of both the emitter and BSF metallisation coverage.

2. Simulation

To evaluate the influence of incomplete metal coverage of the amorphous silicon layers acting either as emitter or BSF, we performed two dimensional numerical simulations using the device simulator Sentaurus TCAD. The a-Si:H layers were modelled as a semiconductor with a band gap of 1.8 eV, two exponentially decaying defect distributions to account for the band tails and two Gaussian distributions describing the dangling bonds with donor and acceptor characteristics. More details on the simulation can be found elsewhere [8]. The metal layers were not explicitly simulated. Instead, we used ”ohmic contacts” without any further definition of a contact resistivity.

A sketch of the simulated IBC-SHJ structure is shown in Fig. 1 on the left hand side. We varied the coverage of either the emitter or the BSF contact metallisation from 50 % to 100 %. When varying one contact, the other was kept constant at 100 %. In Fig. 1 on the right hand side it is shown that regarding the fill factor losses, the variation of the metallisation coverage at the emitter is more critical than at the BSF. While the fill factor only drops by approximately 1.5 % absolute when decreasing the BSF coverage from 100 % to 50 %, the fill factor already drops by 8 % absolute for the same decrease on the emitter. The latter effect was already observed by Desrues *et al.* [9]. Hence we conclude that the coverage of the emitter should be kept at 100 %, while it should be possible to reduce the coverage of the BSF to realize the necessary separation of emitter and BSF contact to avoid shunting of the IBC-SHJ solar cell.

3. Experimental

3.1. Solar cell fabrication

We fabricated 1 cm^2 IBC-SHJ solar cells on 3 Ω cm n-type float-zone material with ¡100¿ orientation. The front side of the approximately 280 µm thick wafer is passivated by an SiN_x/SiO_2 stack and a diffused front surface field. The a-Si:H emitter covers 60 % of the solar cells back side and the BSF 40 %. Both, the emitter and the BSF feature an intrinsic buffer layer of 4-5 nm and were deposited using plasma enhanced chemical vapour deposition (PECVD). The metallisation of the layers is realised by 1.5 µm of thermally evaporated aluminium. While keeping the emitter contact fraction at 100 %, the contact fraction of the BSF is about 65 % for the BSF. A sketch of the resulting solar cell structure is shown in Fig. 2 in the inset. All structuring was realised via photolithography.

3.2. Solar cell results

The solar cells were measured at Fraunhofer ISE CalLab in Freiburg and an independently confirmed efficiency of 19.4 % could be reached. The *FF* of 77.7 % is a very good value, especially when considering that intrinsic buffer layers are present both beneath the emitter and BSF. The j_{SC} is on a reasonable level with 39.2 mA/cm^2 although still relatively low for an all back contacted device. Concerning the V_{OC}, the

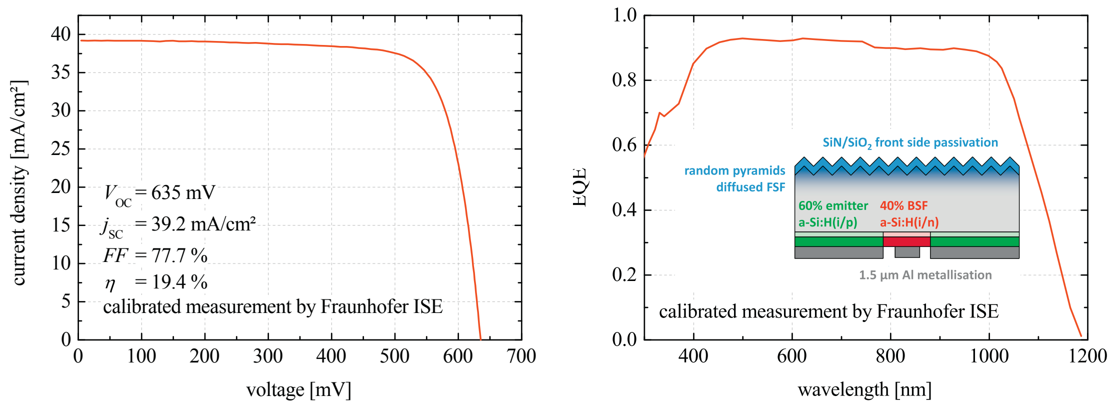


Fig. 2. Left: calibrated *j*-*V*-measurement by Fraunhofer ISE at STC. Right: External quantum efficiency of the same solar cell. In the inset: schematic cross section of the solar cell structure.

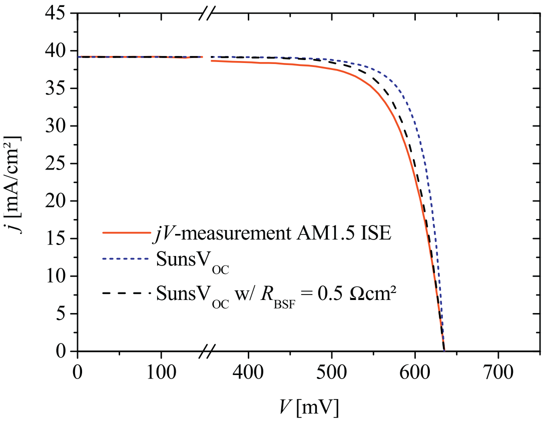
introduction of intrinsic buffer layers should enable much higher values than the measured 635 mV. A loss analysis for each parameter will be examined in detail in the next section.

3.3. Loss analysis

The main mechanism limiting the solar cell's efficiency is the low V_{OC}. During the solar cell process after each deposition or patterning step, a transient photoconductance decay (TrPCD) measurement was carried out, to monitor the evolution of the implied V_{OC} during the cell process. Before the metallisation, the implied V_{OC} was at 700 mV and thereby 65 mV higher than the value of the completed solar cell. This may suggest that there is a strong degradation induced during the metallisation process. However, after back-etching the Al, the implied V_{OC} is at 680 mV, so again on a higher level than the V_{OC} value of the illuminated *j*-*V*-measurement. This effect could be explained, if the band bending induced by the a-Si:H(p) emitter was insufficient. In this case, the passivation of the silicon surface would be reasonably high, resulting in a high implied V_{OC} but the transfer into a high "real" V_{OC} would not be possible due to insufficient band bending. However, a spatially resolved photoluminescence (PL) measurement shows a strong reduction in PL-signal at the cell area. This would not be the case if the low V_{OC} value could be entirely explained by insufficient band bending. Nevertheless, the cause of the enhanced recombination at the cell area and hence the low V_{OC} is still under investigation.

The short circuit current density of the solar cell is reasonably high with a value of 39.2 mA/cm^2. However, for an all back contacted solar cell it should be well above 40 mA/cm^2. Therefore, we measured the reflectance spectrum of the solar cell, weighted it with the AM1.5g spectrum and integrated the current density from 300 to 1100nm. In so doing, we find that the reflected current density is on a low level, as only 1.3 mA/cm^2 are lost due to reflection. As the transmission is negligibly low, the residual current density of 2.6 mA/cm^2 can be attributed to recombination losses at the front side of the solar cell or at the BSF, as well as to parasitic absorption in the aluminium layer regarding the longer wavelenghts.

Concerning the fill factor it can be stated that in general the value of 77.7 % is relatively good for an IBC-SHJ solar cell. However, there is still room for improvement which is obvious when comparing the pseudo-*FF* of 83.1 % obtained from the Suns-V_{OC} characteristic with the *FF* of the illuminated *j*-*V*-measurement. Thus, we can state that loss in *FF* due to transport limitations is larger than 5 $\%_{abs}$. About 3 % are lost due to a relatively high contact resistance at the BSF obtained from TLM measurements. The specific contact resistance of 140 mΩ cm^2 leads to an ohmic contribution of about 0.5 Ω calculated with the area fraction of 28 % of the metallised BSF which is summarised in the table in Fig. 3. The remaining *FF* loss is due to a characteristic similar to that of a solar cell whose *j*-*V*-curve is affected by a low parallel resistance which we assume to stem from the incomplete coverage of the BSF. However, in simulation this



	R_S [Ω]	FF [%]
Suns-V_{OC}	-	83.1
Suns-V_{OC} w/ R_{BSF}	0.5	80.3
measured-jV	0.5 + ”R_P”	77.7

Fig. 3. Left: illuminated jV-characteristic of the best solar cell measured at STC, as well as the characteristic derived by a Suns-V_{OC}-measurement and the jV-characteristic calculated from the Suns-V_{OC}measurement including the series resistance R_{BSF}. On the right: overview of the values for the FF obtained.

characteristic only occurs when the metallisation fraction at the emitter is reduced, which is not the case for this solar cell. Here, further work is needed regarding the simulation to fully understand the effect.

4. Summary

We prepared IBC-SHJ solar cells on n-type absorber using the stack of intrinsic and n-doped amorphous silicon as back surface field (BSF) as well as gap passivation with an independently confirmed efficiency of 19.4 %, mainly limited by a low open circuit voltage. The metallisation fraction at the emitter was kept at 100 % as suggested by our simulation study. The metallisation fraction at the BSF was 65 % which should not have a major influence on the solar cell performance according to our simulation. However, this could not be verified experimentally as the fractional metallisation of the BSF also seems to reduce the fill factor (*FF*). Nevertheless, a *FF* of 77.7 % has been achieved, which is a very good value for this type of solar cell.

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