Reverse Bias Behavior of Diffused and Screen-Printed n-Type Cz-Si Solar Cells

Elmar Lohmüller, Fabian Fertig, Sabrina Werner, Ino Geisemeyer, Florian Clement, and Daniel Biro

Abstract—In this study, we investigate current flow in reverse bias mode and its impact on conversion efficiency for large-area n-type Cz-Si H-pattern and n-type Cz-Si metal wrap through (MWT) solar cells. Shunting is studied as a function of the boron emitter doping profile, and by comparing MWT cells with two different phosphorus-doped back surface field (BSF) structures. Less shunting is observed for cells with deeper boron-doped emitters (depth \( d \approx 500 \) nm) compared to cells with shallower emitters (\( d \approx 500 \) nm). Cells with deeper doping profile have initial shunt resistances of \( R_P < 30 \) k\( \Omega \)cm\(^2\) (without prior reverse load), while cells with shallower emitters exhibit initial values of \( R_P \approx 9 \) k\( \Omega \)cm\(^2\), irrespective of the cell type. Furthermore, cells with deeper boron doping profiles show significantly lower current flows under reverse bias. We observe a halving of the \( R_P \)-values after reverse biasing the H-pattern and the MWT cells with structured BSF where, on the other hand, the conversion efficiencies are hardly affected. MWT cells featuring a BSF below the external p-type contacts show a drop in conversion efficiency of 0.3\%\(_{\text{abs}}\). This is due to degradation of the electrical insulation between via paste and BSF after reverse bias stress.

Index Terms—boron-doped emitter, profile depth, solar cells, H-pattern, leakage current, MWT, n-type silicon, reverse bias.

I. INTRODUCTION

SINCE partial shading of a photovoltaic module can lead to reverse biasing the shaded cells [1], it is important that those cells are not harmed by the applied negative voltage and that the reverse behavior is not detrimental to the module.

This study focuses on the reverse bias behavior of n-type Czochralski-grown silicon (Cz-Si) H-pattern and metal wrap through (MWT) solar cells, sketched in Fig. 1. The current under reverse bias as well as its impact on the conversion efficiency at one sun are investigated by comparing two boron-doped emitters with different doping profiles. In addition, the comparison of these emitters addresses shunting, which can be caused by, for example, the front metallization.

Furthermore, two different rear structures for the MWT cells are compared with respect to shunting and reverse bias stability: MWT cell type A (MWT-A, Fig. 1b) features a structured phosphorus-doped back surface field (BSF), whereas cell MWT-B (Fig. 1c) exhibits a full-area phosphorus-doped BSF. For both MWT structures, a silver-based via paste is applied for metallization of the vias and acts as the external p-type contact. In order to avoid shunting, the via paste must not form an electrically conductive contact to the adjacent n-type-doped region under forward bias. In previous experiments, special test structures have been used to examine the influence of reverse biasing on the electrical contact insulation between BSF and external p-type contacts [2]. A strong degradation of the electrical contact insulation was observed for the rear contact setup corresponding to cell MWT-B.

In this work, the shunting behavior of the two different rear structures for the MWT cells is investigated on cell level. Also, the shunting caused by the front metallization–relevant to the H-pattern as well as the MWT cells–is addressed by comparison of two boron-doped emitters with different doping profiles. In addition to global measurements of forward and reverse current-voltage (\( I-V \)) characteristics, spatially resolved dark lock-in thermography (DLIT) [3] measurements are performed. A thermal simulation of implied hot spot temperatures in a solar module concludes the investigations.

This work was supported by the German Federal Ministry for Economic Affairs and Energy within the research project “THESSO” under contract number 0325491. Elmar Lohmüller thanks the “Reiner Lemoine Stiftung” for the funding of his dissertation.

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II. APPROACH

A. Solar Cell Fabrication

The H-pattern and MWT solar cells were fabricated using pseudo-square n-type Cz-Si wafers with an edge length of 156 mm, a diameter of 200 mm, an initial thickness of 200 µm, and a specific base resistance of $\rho_{\text{base}} \approx 5 \, \Omega \, \text{cm}$.

The procedure is depicted in Fig. 2. Following alkaline texturing, the differently doped front and rear sides were formed by tube furnace diffusion processes with first, a boron tribromide (BBr3), and then a phosphorus oxychloride (POCl3) source. The necessary diffusion barrier layers were formed by plasma-enhanced chemical vapor deposition (PECVD) [6]. For the MWT-A cells with structured phosphorus-doped BSF, the rear-side diffusion barrier was structured prior to POCl3-diffusion using inkjet-printed masking resist and buffered hydrofluoric acid. For BBr3-diffusion, two processes with different peak temperatures were used while keeping the remaining process parameters unchanged. The temperature difference resulted in emitter doping profiles with different maximum near-surface doping concentrations $N_{\text{max}}$ and different profile depths $d$; see Fig. 3. The resulting sheet resistances were $R_{\text{sh}} \approx 70 \, \Omega/\text{sq}$ for emitter B500 ($N_{\text{max}} \approx 1.0 - 10^{20} \, \text{cm}^{-3}$, $d \approx 500 \, \text{nm}$) and $R_{\text{sh}} \approx 40 \, \Omega/\text{sq}$ for emitter B700 ($N_{\text{max}} \approx 1.3 - 10^{20} \, \text{cm}^{-3}$, $d \approx 700 \, \text{nm}$). All cells received POCl3-diffusion ($R_{\text{sh}} \approx 75 \, \Omega/\text{sq}$), during which their boron doping profiles did not alter significantly [6].

In each case, the borosilicate glass (BSG) and phosphosilicate glass (PSG) were removed in HF solution along with the diffusion barrier layers. The passivation layers on the front and rear sides were applied by PECVD. Subsequently, laser drilling of the vias for the MWT cells was performed.

For screen printing, commercial metal pastes were used. The H-pattern cells (Fig. 1 a) were metallized with a three busbar grid on both sides by applying a silver-aluminum paste on the front and a silver paste on the back. The rear side of the MWT cells (Fig. 1 b,c) was metallized by a two-step screen printing process. First, the finger structures were printed with a fire-through silver paste, followed by the simultaneous printing of the external p-type and n-type contacts, as well as the vias with a non-fire-through silver via paste [2]. The front grid, with three thin pseudo-busbars, was screen-printed with a silver-aluminum paste. The same pastes were used for both cell types and also, the same grid structures were applied to metallize boron-doped emitters B500 and B700.

The contact formation was performed in a fast firing furnace and was followed by laser edge isolation on the front.

B. Current-Voltage Measurements

First, measurements of the global forward and reverse $I$-$V$ characteristics were performed. The n-type Cz-Si H-pattern and MWT cells were tested with an industrial cell tester, following the measurement steps outlined in TABLE I.

Initially, measurements on the cells were made without applying prior reverse bias (a). In order to characterize the influence of reverse bias on the forward $I$-$V$ characteristics, 20 measurements on the cells were subsequently made after initially applying reverse bias load (b).

For the determination of shunt resistance values $R_p$, the slope of the dark $I$-$V$ characteristics is fitted at the zero-point of the voltage; $R_p$ is then given by the inverse of the fitted slope. The pseudo fill factor $pFF$–which is free of losses due to series resistance contributions–is determined via Suns-$V_{OC}$ measurements [7].

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1 x forward measurement (no prior reverse bias)</td>
</tr>
<tr>
<td>b</td>
<td>20 x forward measurement (each with initial reverse bias)</td>
</tr>
</tbody>
</table>

TABLE I

OVERVIEW OF THE $I$-$V$ MEASUREMENTS WITH DURATION OF 90 MS FOR THE FORWARD MEASUREMENT AT ONE SUN AND 20 MS FOR THE DARK REVERSE BIAS MEASUREMENT. THE REVERSE MEASUREMENTS WERE PERFORMED UP TO A VOLTAGE OF -14 V OR A CURRENT OF 11 A. THE INTERVAL IN-BETWEEN EACH OF THE 20 MEASUREMENTS IN B WAS 4 S.
C. Dark Lock-In Thermography Measurements

For typical silicon solar cells, DLIT images recorded at a phase of ~90° are proportional to the locally dissipated power [3], generated by local current flow. Hence, current flow can be depicted spatially, which can help to better understand the globally measured I-V values, as discussed in the previous section. A description of the different procedures used in DLIT measurements follows.

III. RESULTS & DISCUSSION

A. Forward I-V Characteristics

I-V measurements were performed following the procedure depicted in TABLE I. The resulting conversion efficiencies η at one sun are between 18% and 19% for the investigated H-pattern and MWT cells.

The influence of reverse bias on the forward behavior of the I-V characteristics is summarized in TABLE II. The absolute losses in η, FF, and pFF and the Rp-values, given in absolute numbers, after the first and twentieth measurements are compared. The changes in open-circuit voltage V_{OC} are very small (|ΔV_{OC}| < 0.4%Δη) and are therefore not shown. That is, no significant increase of the dark saturation current density j_{01} of the first diode in the two-diode model is observed due to reverse biasing. The short-circuit current densities j_{SC} are constant throughout and, thus, are also not shown.

All cells with boron-doped emitter B500 show initial shunt resistance values of Rp ≈ 9 kΩcm² for the first measurement without prior reverse load. In contrast, the cells with emitter B700 exhibit clearly higher shunt resistance values with Rp > 30 kΩcm². The significant difference in Rp shows that the cells with emitter B700 are less sensitive to shunting than cells fabricated with emitter B500. Among the different cell structures, no significant difference in Rp is observed for the respective emitters. It is noteworthy that the Rp-value of the MWT-B cells is at a comparable level with the H-pattern and MWT-A cells for the first measurement (the measurement without prior reverse bias).

After the first measurement with initial reverse bias, Rp decreases to slightly more than half of its initial value for the H-pattern and MWT-A cells, irrespective of the emitter. For the MWT-B cells with emitter B700, Rp decreases to approximately a tenth of its original value. The rather moderate losses in pFF are |ΔpFF| ≤ 0.4%Δabs. Losses in FF are almost equivalent. The MWT-B cells with emitter B700 show the most pronounced pFF-loss, whereas the H-pattern and MWT-A cells each with emitter B700 show the least.

Losses in pFF can, in principle, be caused by increased ohmic leakage currents and/or increased recombination in the space charge region, which leads to an increase of the dark saturation current density j_{02} of the second diode in the two-diode model. The decrease of Rp shows that the ohmic leakage currents have definitely increased. However, application of the two-diode model suggests that the losses in pFF for the H-pattern and MWT-A cells with emitter B700 are mainly caused by slightly increased j_{02}-values, since the Rp-values are still sufficiently high (i.e., the ohmic leakage currents are still sufficiently low). For emitter B500, both increased ohmic leakage currents and slightly higher j_{02}-values are needed to justify the losses in pFF corresponding to the two-diode model.

In comparison with the value of Rp after the first measurement with initial reverse bias, it can be seen that it only slightly decreases after performing 20 measurements for the H-pattern and MWT-A cells and both emitters. This indicates that the ohmic leakage currents are clearly changed by the very first reverse load only for those two structures. The maximum observed FF-loss between initial measurement without reverse bias and last measurement with reverse bias is given by ∆FF = -0.3%Δabs for the H-pattern and MWT-A cells; the maximum FF-loss for the cells with emitter B700 is lower with ∆FF = -0.2%Δabs. Thus, the conversion efficiencies η measured at one sun are almost not affected by reverse bias stress for the H-pattern and MWT-A cells and both emitters (|Δη| ≤ 0.1%Δabs).

In contrast to these two cell types, cell structure MWT-B shows a higher sensitivity towards reverse biasing. As already mentioned, the Rp-values decrease from initial values of Rp ≈ 30 kΩcm² to approximately a tenth after a single reverse load (Rp ≈ 3 kΩcm²). Further reverse biasing leads to further increased leakage currents at the external p-type contacts, as will be shown later. Consequently, an additional drop in Rp (down to Rp ≈ 1 kΩcm²) occurs. As a result, pFF and FF drop by about 1%Δabs and η is decreased by 0.3%Δabs.

We attribute the higher Rp-values (i.e., lower ohmic leakage currents) for cells with emitter B700 to less shunting of the n-junction by metal spikes/crystallites. These form during the firing process and can penetrate deeply into the silicon surface [8,9]. The scanning electron microscope picture in Fig. 4 shows, exemplarily, the imprints caused by spikes/crystallites from the silver-aluminum (Ag-Al) paste on

<table>
<thead>
<tr>
<th>Cell type</th>
<th>BR ratio</th>
<th>Reverse bias</th>
<th>Δη (abs)</th>
<th>ΔFF (abs)</th>
<th>ΔpFF (abs)</th>
<th>Rp (kΩcm²)</th>
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</thead>
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<td>H-pattern</td>
<td></td>
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<td>-0.2</td>
<td>-0.2</td>
<td>4.6</td>
</tr>
<tr>
<td>MWT-A</td>
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<td>initial values</td>
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<td>-0.1</td>
<td>0.0</td>
<td>27.9</td>
</tr>
<tr>
<td>MWT-B</td>
<td></td>
<td>initial values</td>
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<td>-0.2</td>
<td>-0.1</td>
<td>26.5</td>
</tr>
</tbody>
</table>

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B. Dark Reverse I-V Characteristics & DLIT Measurements

Fig. 5 shows the dark I-V characteristics under reverse bias of the first and the twentieth measurements according to the sequence of steps depicted in TABLE I for the H-pattern and MWT cells.

A significant current increase occurs at voltages below \(-4\) V for the H-pattern and MWT-A cells with shallower boron-doped emitter B500, whereas the cells with deeper emitter B700 show significantly lower currents (Fig. 5a-d). No significant differences between first and twentieth reverse bias measurements are observed for the H-pattern and the MWT-A cells. Thus, emitter B700 results in lower current flow under reverse bias.

By comparing the dark reverse I-V characteristics of the MWT-A cells (Fig. 5c) and the MWT-B cells (Fig. 5e) with emitter B700, the curves for the first reverse bias measurement are similar up to a voltage of \(-4\) V (at least for two of the MWT-B cells). For more negative voltages, a strong current increase is observed for the MWT-B cells. This strong current increase can mainly be attributed to the external p-type contact pads metallized with the silver via paste, as illustrated by the DLIT image in Fig. 6e. The twentieth reverse bias measurement shown in Fig. 5f reveals an even earlier current increase for the MWT-B cells compared to the first reverse bias measurement in Fig. 5e. This is in contrast to the findings for the H-pattern and MWT-A cells (Fig. 5a-d).

The DLIT images in Fig. 6 depict the current flow under reverse bias spatially resolved. The H-pattern and MWT-A cells with emitter B500 (Fig. 6a,c) show an area with current flow close to the wafer center. The causes for the occurrence of such rather “well-defined” local current-carrying areas have so far not been clearly identified. One hypothesis is that in these areas, the emitter profile depth is lower in comparison to the remaining front surface. This leads to higher current flow under reverse bias condition. As further experiments were performed with cells featuring an emitter doping profile similar to emitter B500, such rather “well-defined” local structures were not observed (see e.g. Fig. 8c). However, the global reverse I-V behavior measured for those cells is...
consistent with the previously discussed cells with emitter B500.

C. DLIT Measurements II

In order to distinguish the previously discussed contributions of \(R_p\) and \(j_{02}\) to the observed \(pFF\)-losses after reverse biasing, detailed DLIT measurements were performed. The decrease in \(pFF\) is either caused by increased \(j_{02}\)-values, which signals should be prominent in DLIT images taken at a voltage of \(+0.5\) V but not for \(-0.5\) V, or by more pronounced shunts which are linear in voltage (ohmic shunts) that should exhibit the same current flow at a voltage of \(+/-0.5\) V.

The performed DLIT measurement sequence started with images taken at a voltage of \(+/-0.5\) V using initially not reverse-loaded cells. Subsequently, DLIT images with stepwise increased negative voltages up to at least \(-6\) V were recorded, followed by the repeated measurements at a voltage of \(+/-0.5\) V.

1) MWT Cells

The performed DLIT measurement sequences for initially non reverse-loaded MWT-A and MWT-B cells with emitter B700 are depicted in Fig. 7.

No clear signals at a voltage of \(+/-0.5\) V are observed for cell MWT-B (Fig. 7a,b). For cell MWT-A, very weak signals at the external p-type contact pads are observed for a voltage of \(+0.5\) V, but not for \(-0.5\) V. This indicates that slightly higher recombination occurs in these areas (less shielding of the metallized pads by the non-existing BSF in comparison to cell MWT-B). Up to this point, both MWT cells show no significant ohmic shunts.

At a voltage of \(-4\) V, weak signals at the external p-type contact pads begin to appear for the MWT-B cell (Fig. 7d); distinct signals and thus high current flow arise for the measurement at \(-6\) V (Fig. 7e). For the MWT-A cell, weak signals only occur at \(-6\) V, which are partly not correlated to the external p-type contact pads. This also applies to the measurements at \(-8\) V and \(-10\) V for the MWT-A cell, which are not shown.

The subsequently repeated measurements at voltages of \(+/-0.5\) V are shown in Fig. 7f,g. For the MWT-B cell, significantly higher current flow occurs in the area of the external p-type contact pads compared to the initial measurements in Fig. 7a,b. We detect for \(+0.5\) V the same signal strength as for \(-0.5\) V. That is the same power dissipation and thus magnitude of the current flow regardless of the sign of the applied voltage. This ohmic shunting behavior originated from the stress of the reverse biasing that was experienced by the MWT-B structure. For the MWT-A cell, the DLIT images at \(+/-0.5\) V after reverse bias stress almost do not differ from the corresponding images before reverse loading.

This investigation clearly demonstrates that reverse biasing leads to the degradation of the electrical contact insulation between phosphorus-doped BSF and external p-type contact pads for the MWT-B cells. This confirms the results obtained earlier using special test structures [2]. The increased leakage currents at the external p-type contact pads explain the significant losses in \(pFF\) of more than \(1\%_{abs}\) for the MWT-B cells, as previously discussed and given in TABLE II.

2) H-pattern Cell

The described DLIT measurement sequence was also applied to an H-pattern cell with a B500 emitter, which had not been reverse biased before. This was done in order to exemplarily investigate the influence of reverse bias on shunting at the cell’s front in more detail. Again, DLIT images were recorded at voltages of \(+/-0.5\) V prior to and following reverse bias of up to \(-7\) V was applied in steps.

For this investigation, an H-pattern cell fabricated in another cell batch was used. The fabrication process was very similar to the process sequence shown in Fig. 2, with the only

![Fig. 7. DLIT images recorded at a phase of \(-90^\circ\) obtained for a MWT-A and a MWT-B cell with emitter B700 which have not been exposed to reverse load previously. Only the upper half of the middle contact row with the external p-type contact pads—as indicated in Fig. 6e—is shown for each applied voltage. The measurement sequences start with a) and end with g). For the MWT-A cells, also \(-8\) V and \(-10\) V are applied (not shown). Please note that the images c)-e) have a different scaling compared to the other images.](image)

![Fig. 8. DLIT images recorded at a phase of \(-90^\circ\) obtained for an H-pattern cell with emitter B500 which has not been exposed to reverse load previously. The images show an interesting cutout over the entire cell width. As described in the text, however, this cell comes from an almost equally processed cell batch explaining the differences between image c) and Fig. 6a. Emerging ohmic shunts while/after reverse bias are marked with arrows in c)-e). Please note that image a) has a different scaling compared to the other images.](image)
difference being in the POC₁₃-diffusion process. It included, among others, higher peak temperatures. Thus, the emitter depth is increased by a maximum of ≈ 20 nm, in comparison with the previously investigated cells with emitter B500.

By comparing the respective DLIT images captured at +0.5 V (Fig. 8a,d) and -0.5 V (Fig. 8b,e), new ohmic shunts are clearly visible after reverse bias was applied (marked with arrows). These ohmic shunts are also visible in the image taken at -7 V (Fig. 8c). When studying the difference image of Fig. 8b and Fig. 8e, it can be seen that only clear signals remain at the spots where the newly created ohmic shunts are marked. This also applies to the difference image of Fig. 8a and Fig. 8d. By creating the difference image of the shunt-corrected DLIT images of Fig. 8a and Fig. 8d, no clear signals, besides noise, remain. Thus, the value of \( J_{02} \) does not significantly increase locally after reverse bias stress.

D. Simulation of Hot Spot Temperature

In order to investigate the potential impact of the observed reverse behavior on module reliability, resulting hot spot temperatures are estimated by means of thermal simulation.

To determine realistic operating points of the shaded cells in question, we consider the cells to be assembled within a standard industrial module with 60 cells connected in series and divided into three strings with a certain arrangement of bypass diodes. That is, if one cell is fully shaded, it is stressed in reverse by the other, non-shaded cells until the set-on voltage of the bypass diode is reached (\( V \approx -12 \) V), or until the shaded cell conducts the short-circuit current of the other, unshaded cells (\( I \approx 9 \) A) [1].

Fig. 9a,b show corresponding DLIT images for the addressed operating points under full shading conditions for H-pattern cells with emitters B500 and B700, respectively. In order to estimate the resulting hot spot temperatures in a solar module, we calibrated these images to locally dissipated power and simulated the resulting temperatures in a solar module with a thermal module model [11]. We assume full shading of the cells depicted in Fig. 9a,b, an illumination level of 1 sun for the surrounding non-shaded cells and a wind flow of 1 m/s on the module’s front and rear side. This leads to a module temperature of 48°C in the non-shaded part of the module. Furthermore, we assume the power sources on the shaded cells to be temperature-independent. That is, the values determined from the DLIT measurements performed at 25°C are used as a constant input for the simulation.

Fig. 9c,d show the results of the performed thermal simulation for the temperature fields as they would be measured on the module’s backsheet. While the cell with emitter B700 results in simulated peak temperatures of less than 90°C, the cell with emitter B500 reaches values well above 250°C, which would severely damage a standard industrial module. Hence, it can be concluded that the fabricated H-pattern cells with emitter B700 are unlikely to result in hot spot risk and therefore, should not impact module reliability. However, cells with a B500 emitter constitute a large risk to module reliability due to potential hot spot heating. The same results are also expected for the MWT-A cells since their reverse bias behavior is comparable with that of the H-pattern cells. The homogeneous current flow at the external p-type contact pads under reverse bias for cell structure MWT-B could be potentially used as an integrated bypass-diode approach. For such an application, the forward leakage currents have to be significantly reduced.

IV. Conclusion

We investigated the current flow under reverse bias and its impact on conversion efficiency at one sun for large-area n-type Cz-Si H-pattern and MWT solar cells. Shunting was studied on the one hand as a function of the emitter doping profile by using two different boron diffusion processes, and, on the other hand, by comparing two different phosphorus-doped BSF structures in case of the MWT cells.

Less shunting is observed for cells with boron-doped emitter B700 (depth \( d \approx 700 \) nm, maximum near-surface concentration \( N_{\text{max}} \approx 1.3 \times 10^{20} \) cm\(^{-3}\)) compared to cells with emitter B500 (\( d \approx 500 \) nm, \( N_{\text{max}} \approx 1.0 \times 10^{20} \) cm\(^{-3}\)). The cells with deeper emitter B700 have initial shunt resistance values of \( R_p > 30 \) kΩcm\(^2\) (without prior reverse load), while the cells with shallower emitter B500 exhibit initial values of \( R_p \approx 9 \) kΩcm\(^2\), irrespective of the cell type.

Reverse stress causes different effects on the investigated cell structures. A drop of \( R_p \) to approximately half of its initial value after single reverse biasing is observed for the H-pattern and MWT cells with structured BSF (MWT-A), independent of the emitter doping profile. Further stressing leads to no further substantial degradation in \( R_p \). The determined losses in pseudo fill factor \( pFF \) and thus conversion efficiency \( \eta \) are small with \( |\Delta pFF| \leq 0.3\%_{\text{abs}} \) and \( |\Delta \eta| \leq 0.1\%_{\text{abs}} \). For the MWT cells with full-area BSF (MWT-B) and emitter B700, \( R_p \) drops

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to $R_p \approx 3 \text{k}\Omega \text{cm}^2$ after single reverse biasing and thus, to a tenth of its initial value. Further reverse biasing leads to a further reduction in $R_p$ down to $R_p \approx 1 \text{k}\Omega \text{cm}^2$. As a result, $pFF$ and $\eta$ are significantly decreased and the losses are given by $\Delta pFF = -1.3\%_{\text{abs}}$ and $\Delta \eta = -0.3\%_{\text{abs}}$. Spatially resolved DLIT measurements show that these $pFF$-losses occur due to clearly increased leakage currents in forward direction in the area of the external p-type contact pads.

Regarding the behavior under reverse bias, the results indicate that deeper boron doping profiles result in significantly lower current flow. As also revealed, high reverse currents do not inevitably lead to reduced conversion efficiencies measured at one sun.

Concerning potential module integration, thermal simulations show that H-pattern cells with deeper emitter B700 are significantly less critical with regards to potential hot spot heating compared to cells with shallower emitter B500. The same finding holds for the MWT-A cell structure, whereas cell structure MWT-B might be potentially used for an integrated bypass-diode approach, in case the forward leakage current can be sufficiently reduced.

ACKNOWLEDGMENTS

The authors thank all co-workers at the Fraunhofer ISE PV-TEC; especially R. Ackermann, S. Bang, W. Hasan, R. Hoenig, M. Jahn, B. Link, S. Schmutzler, F. Schwehr, and D. Trogus.

REFERENCES


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Daniel Biro, born 1972, studied physics at the University of Karlsruhe, Germany and the University of Massachusetts Amherst, USA. He received his Ph.D. degree from the University of Freiburg in 2003 in the field of silicon solar cell diffusion technologies. In 1995 he joined the silicon cell characterization group at Fraunhofer ISE. In 1999 he started working in the silicon solar cell production technology group of Fraunhofer ISE. In 2004/2005 he coordinated the design and ramp-up of the production oriented research platform PV-TEC and is now head of the department “Thermal, PVD and Printing Technology / Ind. Cell Structures” at Fraunhofer ISE.