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Investigation of the effect of p/n-junctions bordering on the surface of silicon solar cells

R. Kühn, , A. Boueke, M. Wibral, C. Zechner, P. Fath, G. Willeke, E. Bucher,
University of Konstanz, Faculty of Physics, P.O. Box 5560, 78434 Konstanz, Germany
Phone : ++49-7531-882260 Fax : ++49-7531-883895 e-mail : Ralph.Kuehn@uni-konstanz.de

ABSTRACT: In recent times several solar cell structures containing holes within the cell have been proposed. POWER [1] as well as EWT [2] solar cells suffer from an relatively low V_{oc} and an unsatisfying fill factor if no special care is taken. All these devices have in common open pn-junction at neighbouring p and n type regions at cell surface which run over a long distance. This is due to interdigitated n- and p type regions for back-contact EWT cells or due to finger-like base contacts at the cell rear side of POWER solar cells. Aim of this study was to investigate the possible deteriorating effect of this long open pn-junction as a possible explanation for low FF and Voc of these novel devices. An experimental model device based on the POWER solar cell concept was used which enables the simple drilling of holes in the cell emitter and thus enhancing the length of the open pn-junction borders by increasing the number of holes. IV-measurements of experimental devices as well as two dimensional computer simulations clearly prove the above hypothesis. It could be shown that a high second diode saturation current is responsible for negative impact on the cell performance.

Keywords : junction edge effect - 1 : characterization -2 : simulation -3

1. INTRODUCTION

The use of mechanical texturization tools as well as laser texturing gives rise to a new flexibility in solar cell design. With differently shaped blades or a special structuring wheel [4] mounted on a conventional dicing saw a V-grooved structure can be cut into the surface of a silicon solar cell. The groove distance and depth as well as the V-groove angle is variable. In the POWER (Polycrystalline Wafer Engineering Result) solar cell concept [1] the front and the rear surface of a silicon wafer are structured with perpendicularly running grooves. When the groove depth exceeds a certain limit holes appear at the crossing points of the front and rear grooves. These holes serve two purposes. They give rise to an optical semitransparency of the solar cell reaching up to 30%. New applications especially in solar architecture are envisaged. In the bifacial POWER solar cell [4] the holes serve as an electrical interconnection of the front and the rear emitter.

In EWT (Emitter Wrap Through) solar cells [3] holes are formed by laser drilling to interconnect the front emitter with the rear side. All electrical contacts can be placed at the rear side of the solar cell. The main advantages of the EWT cell are a higher J_{sc} due to the vanishing shading losses at the front surface and a simpler interconnection of the solar cells within a module.

Both POWER as well as EWT solar cells show a poor V_{OC} below 550mV if no special care is taken [2], [4]. At the same time the low fill factor of less than 70% reduces the efficiency of the cell. A feature that both solar cell designs share is the fact that the pn-junction borders to the surface not only at the margins of the cell as it is the case for conventional solar cells. On the contrary the pn-junction regions border on the surface of the cell in the regions where p- and n-type regions are neighbouring. This is the case in EWT solar cells where interdigitated contacts on the rear side of the cell are printed on p- or n-type regions respectively. In POWER solar cells the holes connect the n-type emitter of the front to the rear side where it is neighbouring to the p-base region underneath the rear side contacts.

The present work will examine the influence of these regions where the pn-junction borders on the surface on the solar cell performance.

2. EXPERIMENT

Semitransparent POWER solar cells with different hole densities have been produced. Fig. 2 schematically shows the processing and characterisation sequence of this study.

The front side of 300µm thick Cz-Si wafers is textured mechanically using a conventional dicing saw. The depth of the texture amounts to 150µm. After saw damage removal the wafers are $POCl_3$-diffused. The front and rear contact grid is formed by screenprinting. Some cells were coated with a PECVD silicon nitride ARC. Its passivating effect especially in the later hole regions was to be investigated. After IV- characterisation the rear side of the cell was textured with a depth of 100µm. This depth is to low to create holes but the effect of the induced saw damage can be studied. In a second step a deeper texturization is performed creating holes. The number of holes is increased step by step by cutting an increasing number of grooves on the rear side followed by a characterisation of the solar cells. With each structuring step the distance between the holes is reduced which means that the hole density increases. The size of the quasi-square holes is 140x170µm².

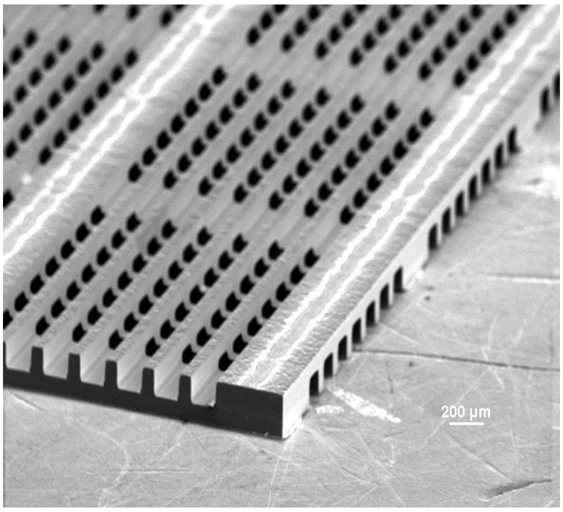

Fig. 1: SEM-picture of a POWER solar cell with a structure similar to the one of the cells investigated in this work.

Stage	trans-mittance	length of pn-junction at the surface	hole distance
1) rear not textured	0 %	0mm	--
2) rear textured, no holes	0%	0mm	--
3) rear textured, holes	2.0%	1250mm	2.4mm
4) rear textured, more holes	6.5%	4600mm	0.8mm
5) rear textured, most holes	11%	6875mm	0.4mm

Tab. 1: Correlation of different parameters for the progressing stages as outlined in Fig. 2.

mechanical texture of the frontside
depth: ½ cell thickness
⇓
saw damage etching
⇓
$POCl_3$ emitter diffusion (30Ω/□)
⇓
screenprinting of front and rear
contact grid
⇓
characterisation *[stage1]*
⇓
mechanical texture of the rearside
depth: < ½ cell thickness
→ no holes
⇓
characterisation *[stage2]*
⇓
mechanical texture of the rear side
depth: > ½ cell thickness
→ some holes
⇓
characterisation *[stage3]*
⇓
mechanical texture of the rear side
depth: > ½ cell thickness
→ additional grooves, more holes
⇓
characterisation *[stage4]*
⇓
and so on ☺

Fig. 2: Processing and characterisation sequence

3. RESULTS AND DISCUSSION

Fig.3 and fig.4 show the dark and the illuminated IV-characteristics for the progressing processing stages.

stage	ΔV_{OC} [mV]	Δ FF [%]	J_{02} [mA/cm²]
1	0	0	$2*10^{-7}$
2	-1 (-1)	-0.6 (-0.8)	$2*10^{-7}$
3	-9 (-9)	-3.7 (-3.7)	$1*10^{-6}$
4	-30 (-28)	-7.1 (-7.6)	$4*10^{-6}$
5	-44 (-48)	-8.8 (-10.9)	$6*10^{-6}$

Tab. 2: absolute decrease in V_{OC} , FF and increase in J_{02} for POWER cells with SiN-ARC in progressing stages. The values in brackets correspond to cells without ARC.

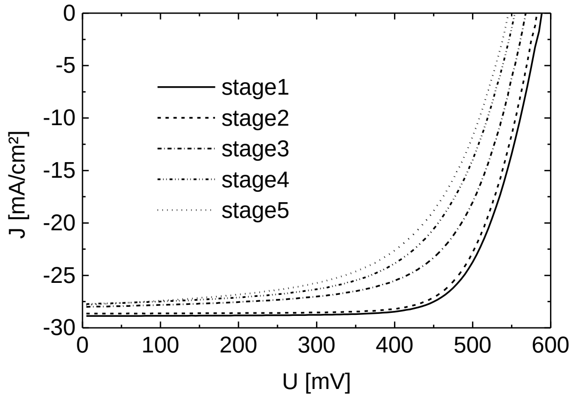

Fig. 3: Illuminated IV-characteristics of semitransparent solar cells with different hole densities. J is corrected by the light losses due to the optical transmittance.

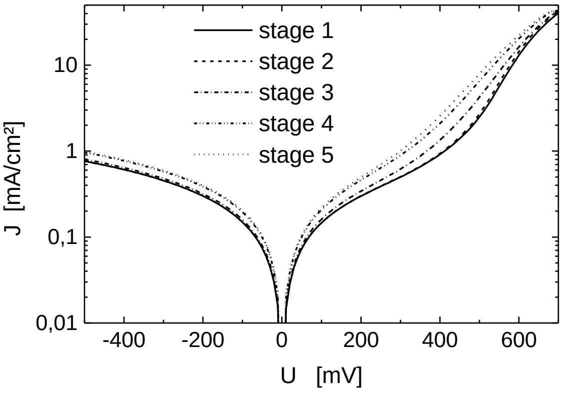

Fig. 4: Dark IV-characteristics of semitransparent solar cells with different hole densities.

It can be recognised that with increasing length of the border of the pn-junction at the cell surface and with decreasing distance between the holes, the FF as well as V_{OC} deteriorates (see Tab. 2). This is mainly due to an increasing saturation current density J_{02} of the second diode. The cells of stage 2 (rear surface texture without creation of holes) show only a very slight loss in FF and V_{OC}. Apparently the induced saw damage on the rear side of the cell does not strongly affect the cell performance.

Fits of the dark IV-curve reveal that J_{02} grows more than one order of magnitude with increasing hole density. The investigated structures still have a saw damage in the rear side grooves which can not be etch as the cells are already metallized. This saw damage seems to be mainly responsible for the deteriorating effect of the open pn-junctions. Fig. 5 compares a non-rear-textured cell (stage1), a POWER solar cell (stage 5) with saw damage in the rear side grooves and a bifacial POWER cell [4] where the saw damage is etched and the entire surface is passivated by a PECVD silicon nitride. Obviously the junction edge effects are much less deteriorating for the later POWER cell.

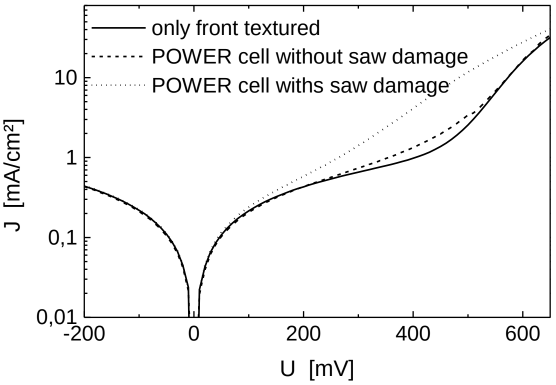

Fig. 5: Dark IV-characteristics of a front textured cell, a bifacial POWER cell without saw damage and a POWER cell (stage 5 of this study) with saw damage in the rear side grooves.

4. COMPUTER SIMULATIONS

Using DESSIS^{TM} POWER solar cells with different hole densities have been simulated. The influence of the distance between the holes was investigated. Special emphasis was put on the question whether the saw damage in the rear side grooves has a significant influence or not. Additionally the impact of a passivating layer especially in the surface pn-regions has been simulated.

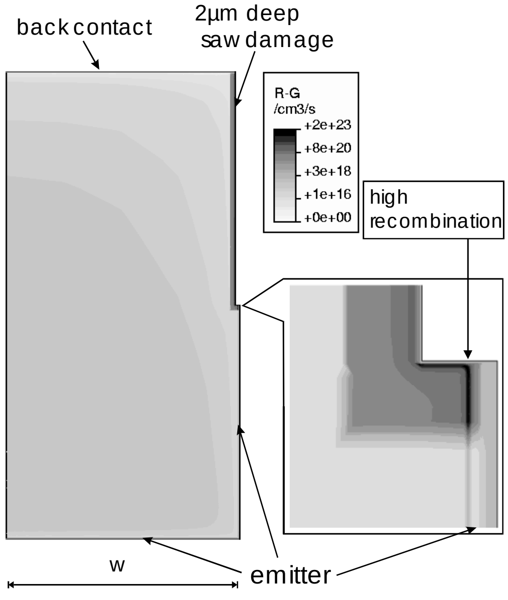

Fig. 6: Unit cell used for the simulations. The enlargement shows the total recombination rate in the critical region around the pn-junction bordering on the cell surface.

Fig. 6 shows the simulated unit cell. The width W of the cell is varied between 100 - 2400µm. The emitter covers the front side and the upper half of the right side.

The junction borders on the surface at the edge on the middle of the right side. On the lower half of the right side a 2µm deep saw damage is optionally simulated. On the cell surface, different surface recombination velocities and surface charges were assumed to simulate cells with and without a silicon nitride passivation layer. In order to exclude the influence of lateral series resistances within the emitter , non-shading contacts which cover the entire front and rear side were chosen for the simulation. The surface recombination velocity underneath the contacts is fixed on 10^7cm/s.

Figure 7 shows the results of the computer simulations. Several main conclusions can be drawn:

- to minimise the negative impact of the junction edge effects, the saw damage in the rear grooves must be removed and a good surface passivation has to be applied.
- without any surface passivation especially the fill factor suffers from the junction edge effects. This can be explained by an increasing saturation current of the second diode. The enlargement in Fig. 6 shows the very high recombination rate in the region where the junction borders on the cell surface when a saw damage exists in this area.
- an existing saw damage in the rear side grooves deteriorates the cell characteristics. V_{OC} as well as FF become smaller with decreasing groove distance.
- the worst case appears if a passivating layer with a high charge density of 10^{12}C/cm² (typical for PECVD silicon nitride) is precipitated over a saw damaged area with a junction edge. Cell efficiency can be reduced up to 25% due to a lowered V_{OC} and FF.

5. CONCLUSIONS

Semitransparent POWER solar cells with different hole densities have been fabricated and characterised. The V_{OC} and the FF decrease with an increasing hole density by up to 48mV or 10.9% respectivly for a POWER cell with 11% optical transmittance. This reduction is mainly due to an increased saturation current J_{02} of the second diode. J_{02} grows when the pn-junction borders on the cell surface with its high recombination velocity. These junction edge effects are especially harmful if the saw damage in the rear side grooves is not etched. A very efficient surface passivation especially in these regions as it is realised for bifacial POWER solar cells [4] seems to be indispensable. 2-dimensional computer simulations support these results.

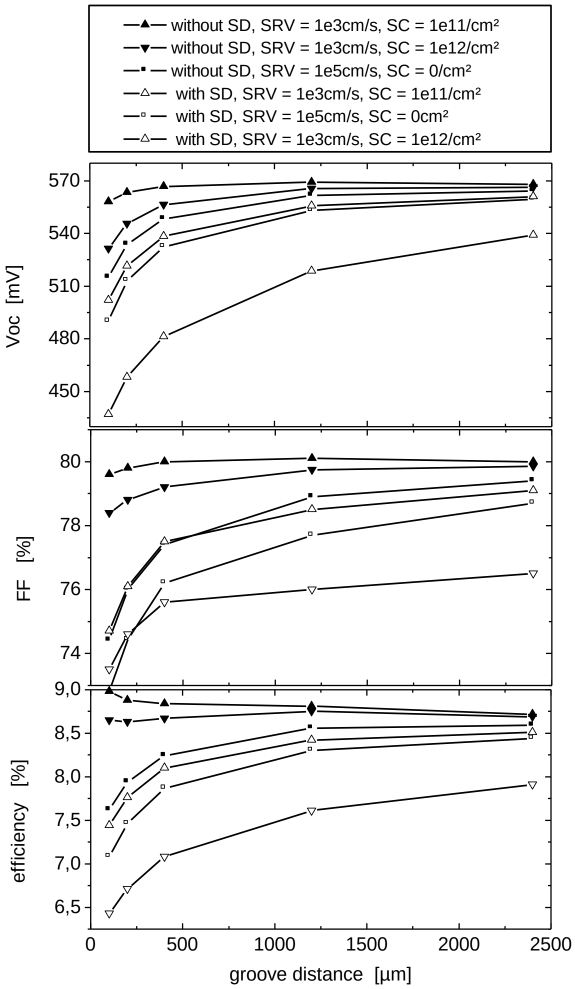

Fig. 7: Results of the computer simulations. Cells with and without a saw damage (SD) in the rear side grooves, with different surface recombination velocities (SRV) and surface charge densities (SC) are simulated for different groove distances.

REFERENCES:

[1] G. Willeke, P Fath :The POWER silicon solar cell concept, Proc. 12th European PVSEC, Amsterdam 1994

[2] A. Schönecker, H.H.C.de Moor, A.R. Burgers, A.W. Weeber, J. Hoornstra, W.C. Sinke, P. Michiels, R.A.Steeman: An industrial multi-crystalline EWT solar cell with screenprinted metallisation; Proc. 14th European PVSEC, Barcelona 1997

[3] P. Fath, C. Marckmann, E. Bucher, G. Willeke : Multicrystalline silicon solar cells using a new high throughput mechanical texturization technology and a roller printing metallization technique; Proc. 13th European PVSEC, Nice 1995

[4] R. Kühn, A. Boueke, M. Wibral, P. Fath, G. Willeke, E. Bucher: „11% semitransparent bifacially active POWER crystalline silicon solar cells“, to be presented on this conference