THE LAMELLA SILICON SOLAR CELL

B. Terheiden, G. Hahn, P. Fath, E. Bucher
Universität Konstanz, Fachbereich Physik, Fach X916, 78457 Konstanz, Germany
Tel: +49-7531-88-2088, Fax:+49-7531-88-3895
email: barbara.terheiden@uni-konstanz.de

ABSTRACT: The novel LAMELLA solar cell concept is introduced. The main objective is the shortening of the distance between place of carrier generation and the emitter which results in an enhanced carrier collection. Therefore, deep slits are mechnically brought into the front side of the wafer. Especially Bayer RGS (Ribbon Growth on Substrate) benefits strongly from this cell concept. Also mono- and multicrystalline LAMELLA cells have been processed and the impact of different lamella widths has been investigated. Efficiencies of up to 15.9% (monocrystalline silicon, with single ARC) could be achieved.
Keywords: vertical junction - 1: mechanical texturisation - 2: c-Si - 3

1 INTRODUCTION

A low charge carrier collection due to short diffusion lengths is a problem of many types of silicon solar cells. An improvement in short circuit current can be achieved by providing short distances between the place of carrier generation and the emitter. One approach is the vertical junction (VJ) cell which was first introduced in 1970 [1] for space application. In that case the shortening of the diffusion length is due to radiation damage in the silicon wafer. The vertical junction is formed at very narrow, vertical slits brought into the wafer front side. After defining the particular regions anisotropic etching is formed to obtain the lamella structure.

The slit formation in the novel LAMELLA silicon solar cells is done mechanically using a conventional dicing saw. Therefore this technique is independent of crystal orientation and hence is also suitable for multicrystalline, ribbon and other silicon wafers. This opens new possibilities for a short circuit current improvement in silicon solar cells with short diffusion lengths.

Two different LAMELLA cell designs were investigated. They differ in the wafer structure and the applied metallisation concept.

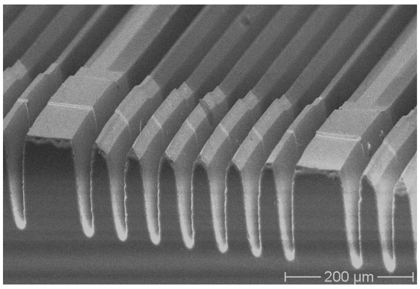

Figure 1: The Scanning Electron Microscope (SEM) picture shows a LAMELLA cell grid fingers lying on plateaus (structure I). The interconnecting cell busbar is visible in the front.

In one case the grid fingers are lying on plateaus (structure I). That means that the structure must have wider lamellas for the finger plateaus and narrower ones for carrier collection enhancement and the reduction of reflectance (Figure 1).

In the other case the grid fingers are formed along one particular side of the sharpened lamella tips (structure II). The finger spacing can be varied by having higher and lower lamellas since only the higher ones will be metallised in a subsequent processing step, (Figure 2).

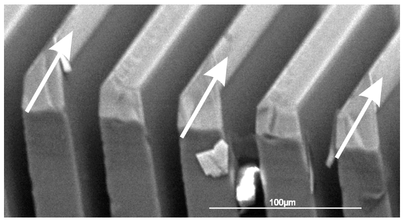

Figure 2: The SEM image shows a LAMELLA cell with the grid fingers lying on one particular side of every second lamella tip marked by arrows (structure II).

2 LAMELLA SOLAR CELL PROCESSING

The LAMELLA wafer are structured with a conventional dicing saw equipped with a very thin sawing blade of 15 µm width. The silicon wafer are 250 µm thick, the slits are 170 µm deep and the lamella width is 50 µm and 100 µm. The sharpening of the lamellas requires either an extended etching step or a second sawing step with a bevelled sawing blade. The lamellas in Figure 1 and 2 are sharpened mechanically while Figure 3 shows etched lamellas.

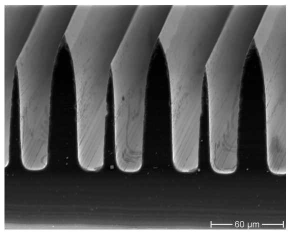

Figure 3: The SEM image shows a LAMELLA cell with grid fingers lying on the right side of every second lamella (structure II). The difference in height and the tip sharpening are the consequence of a long acidic etch.

The disadvantage of the long etching duration is the extreme thinning of the lamellas and the increasing width of the slits.

After the acidic saw damage etch of the mechanically sharpened LAMELLA wafer, the different types of silicon wafer undergo their specific processing sequence for emitter diffusion and surface passivation (Figure 4 and 5).

1. Mechanical LAMELLA texturisation
2. Saw damage etching
3. TLC (Trans1,2-Dichloroethene) thermal oxide masking of rear side
4. $POCl_3$ emitter diffusion: 100 Ω/sq.
5. TLC thermal oxidation: suitable for passivation and antireflection coating
6. Local Al back surface field formation
7. SAP&SAFE (Shallow Angle Photolithography&Shallow Angle Finger Evaporation) or SP (standard photolithography) for oxide opening
8. Evaporation of Ti/Pd/Ag front contacts and busbars
9. Al evaporation of the rear contact, sintering
10. Cell separation

Figure 4: Process sequence for monocrystalline LAMELLA silicon solar cells.

For multicrystalline (mc) and Bayer RGS LAMELLA cells the following processing sequence was applied.

BAYSIX	RGS
1. -	Planarisation
2. Saw damage etch	Damage etch
3. Mechanical LAMELLA texturisation	
4. Saw damage etching	
1. P-Al-codiffusion: 80 Ω/sq.	$POCl_3$ diffusion: 80 Ω/sq.
6. Dry thermal oxidation for surface passivation	
7.	Al evaporation + alloying at rear side
8. SAP&SAFE or SP for oxide opening	
9. Evaporation of Ti/Pd/Ag front contacts and busbars	
10. Al evaporation of the rear contact, sintering	
11. Cell separation	
12. H-passivation	

Figure 5: Process sequence for multicrystalline and RGS LAMELLA silicon solar cells.

The shallow angle photolithography (SAP) is a self-aligning technique. That means the wafer is exposed to light under a shallow angle and one lamella shadows the following one. The SAP step for opening the second thermal oxide (mono-Si) and the thin passivating oxide (mc-Si) respectively is independent of the particular type of wafer. Different thickness' of photoresist and corresponding durations times for light exposure and resist developing were investigated. Combined with this optimisation the most suitable light exposure angle has to be found. Figure 6 gives an idea of the photoresist thickness and two different light exposure times.

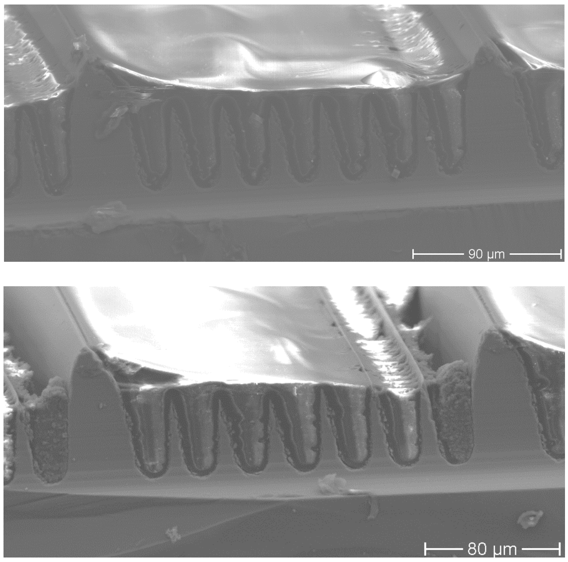

Figure 6: SEM image showing different light exposure times but the same shallow angle. The top SEM image shows the shorter exposure time. The light comes from the left. Therefore the left flank is free of photoresist after developing.

The cell metallisation is carried out applying the shallow angle finger evaporation (SAFE) technique [2]. In this case metal is evaporated under a shallow angle onto the LAMELLA cells. Figure 2 shows a LAMELLA cell which is metallised by a combination of SAP&SAFE with 50 nm of Ti and Pd and 1 µm of Ag on every second lamella. After the lift-off the cells have fine line fingers of about 20 µm width on the illuminated flank of every higher lamella which means every 100 µm.

Besides the shallow angle metallised LAMELLA cells, also LAMELLA cells with a finger grid on plateaus with unmetallised lamellas between the fingers have been processed. The SEM image of Figure 1 illustrates the finger grid. In that case the finger distance is 400 µm.

All LAMELLA cells got an additionally evaporated busbar and a full Al rear contact.

3 CHARACTERISATION

Series of LAMELLA silicon solar cells of structure I and II (area 4 cm^2) have been fabricated and characterised. Besides different lamella widths also the influence of cutting depth and finger spacing was investigated. Additionally the following three different types of silicon material were compared with respect to the impact of short circuit current increase in dependence of the lamella width: Float zone (FZ) and mc silicon (Baysix) as well as Bayer RGS [3].

3.1 Monocrystalline LAMELLA cells

The FZ-LAMELLA cells with diffusion lengths well above the wafer thickness demonstrate efficiencies of almost 16% (Figure 7). Compared to the flat reference cell a loss in fill factor is obvious. This loss is due to an enhanced saturation current of the second diode resulting from the 4 to 7 times increased area of the space charge region.

Another important parameter for comparison is the short circuit current (J_{SC}). The highest J_{SC} of 36.5mA/cm^2 of FZ 1 (structure I) shows the positive effect of the texture. The J_{SC} value of the FZ 2 with the same index is reduced because of a doubled number of grid fingers and the resulting higher reflectance (Figure 8). The shallower slits of FZ 2 does not influence the J_{SC}. The relative small J_{SC} of FZ 3 is also due to a higher reflectance (Figure 8), because of a non-optimal lift off leading to wider grid fingers.

The structure II LAMELLA cells show lower IV-parameter due to problems during oxide opening (Figure 7). The low V_{OC} depends on an incomplete surface passivation because of an unwanted oxide removal. This also causes a higher reflectance and therefore a lower J_{SC}. But the same relation as for FZ 1-3 with respect to the different lamella widths can be seen.

Cell structure / lamella width	V_{OC} [mV]	J_{SC} [mA/cm^2]	FF [%]	η [%]
FZ 1: I/50µm	622	36.5	69.8	15.9
FZ 2: I/50µm, no. of fingers doubled	623	34.6	73.3	15.8
FZ 3: I/100µm	616	32.7	74.2	15.0
FZ 4: II/50µm	584	31.6	61.7	11.4
FZ 5: II/100µm	600	29.6	68.2	12.1
FZ 6: flat reference	644	29.8	78.6	15.1

Figure 7: Illuminated IV-parameter of FZ LAMELLA cells with a non-optimised single antireflection coating (ARC).

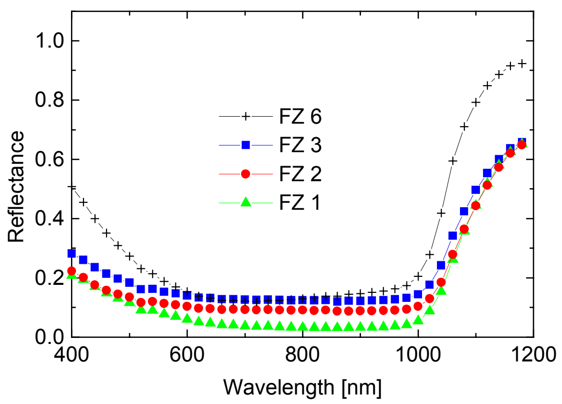

Figure 8: Hemispherical reflectance of FZ-LAMELLA cells with a non-optimal single ARC.

The reflectance (Figure 8) illustrates the effect of light trapping for wavelengths > 1000 nm comparing FZ 6 with the FZ LAMELLA cells. The reflectance is responsible for most of the differences in J_{SC} of the FZ 1-3.

3.2 Multicrystalline LAMELLA cells

The LAMELLA cell concept was also applied to neighbouring mc-Si wafer of the same crystal grain structure. The difference in J_{SC} of Baysix 1 and 2 is caused almost only by the particular reflectance (weighted reflectance: 19.8% and 18.3% respectively). The reflectance of Baysix-LAMELLA cells show an increase in J_{SC} compared to the flat reference (weighted reflectance: 37.6%) which is not only due to the lower reflectance of the LAMELLA cells but also due to an improved carrier collection. In this case it almost does not matter if the lamellas are 50 µm or 100 µm wide because the diffusion length in mc-silicon is even large enough for the 100 µm distances.

Cell structure/ Lamella width	V_{OC} [mV]	J_{SC} [mA/cm^2]	FF [%]	η [%]
Baysix 1: I/100µm	578	29.6	74.6	12.8
Baysix 2: I/50µm	574	31.2	71.5	12.8
Baysix 3: flat reference	591	22.1	78	10.0

Figure 9: Illuminated IV-parameters of Baysix mc LAMELLA cells without an ARC.

3.3 Bayer RGS LAMELLA cells

Since the LAMELLA solar cell concept is especially suitable for silicon wafers with short diffusion lengths the RGS is predominated to demonstrate the benefits of this cell design.

Compared to mc-Si RGS shows a different behaviour concerning the variation of the lamella width. For RGS there is a difference in J_{SC} in dependence on the lamella width. After H-passivation the diffusion length of RGS is in the range of 30 µm and this is more than half of the 50 µm lamella width. Hence carriers generated deeper in the bulk can now be collected in the lamellas.

This leads to a larger improvement in the IQE of RGS 2 than of RGS 1 (Figure 11, weighted reflectance: 30.4% and 26.2% respectively). Therefore, the J_{SC} of RGS 2 increases more than the one of RGS 1 (both originating from the same wafer). Hence an efficiency of 8.4% (without ARC, reflectance Figure 11) was obtained.

Cell structure /lamella width	V_{OC} [mV]	J_{SC} [mA/cm^2]	FF [%]	η [%]
RGS 1:I/ 100 µm	477	15.6	68.8	5.1
RGS 2: I/ 50 µm	465	18.7	68.2	5.9
RGS 1: after H-passivation	511	18.4	71.2	6.7
RGS 2: after H-passivation	508	23.2	71.7	8.4

Figure 10: Illuminated IV-parameter of Bayer RGS-LAMELLA cells without an ARC.

As mentioned above the IQE of RGS 2 improves more than the IQE of RGS 1 after H-passivation. Already before H-passivation the IQE of RGS 2 is higher for wavelengths > 750 nm. This demonstrates that shorter distances to the emitter due to the smaller lamella width positively influence the short circuit current even in that state of solar cell processing.

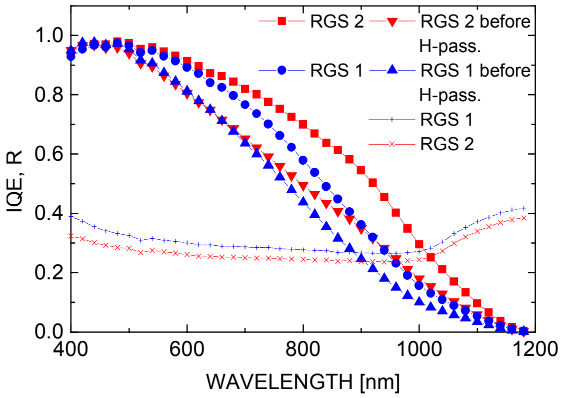

Figure 11: Internal quantum efficiency of Bayer RGS-LAMELLA cells without an ARC before and after H-passivation.

4 CONCLUSION

Two LAMELLA cell designs on different types of silicon wafer have been investigated. The monocrystalline LAMELLA cells show efficiencies of 15.9% (4 cm^2, with single ARC). The LAMELLA structure improves the J_{SC} of the mc-LAMELLA cells compared to the flat reference due to a reduction of reflectance but also due to a higher carrier collection.

The potential of the LAMELLA solar cell concept can be demonstrated on ist best on the RGS ribbon silicon. A cell efficiency of 8.4% (without ARC) was obtained due to the positive influence of the smaller lamellas of 50 µm width.

5 FUTURE PLANS

Because of the low reflectance of shallow angle metallised solar cells this type of LAMELLA cells will be further improved by optimising the oxide opening with SAP. Higher short circuit currents compared to structure I cells will be obtained. Especially the RGS LAMELLA cells will be processed by using SAP&SAFE.

6 ACKNOWLEDGEMENT

We would like to thank B. Fischer for helpful discussions about the characterisation, S. Kühne for the SEM-images and M. Keil for help during LAMELLA cell processing. This work was supported by the German BMWI under contract no. 0329794.

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