Bifacial solar cells on multi-crystalline silicon

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Abstract: In this work we present two different approaches for a bifacial solar cell on mc silicon, the first (n^+pp^+-device) with a phosphorous emitter on the front side, a boron Back Surface Field (BSF) and an open rear contact. The best solar cell processed so far with this structure (100x100 mm² p-type mc-Si wafer, ~200 µm thickness) had an efficiency of η=15.4 % and η=10.2 % under back side illumination. The second solar cell concept (n^+pn^+-device) has a double sided emitter, which is connected via laser drilled holes (by a Nd:YaG laser), similar to the Emitter Wrap Through (EWT) solar cell. The first prototypes of this concept reached an efficiency of 11.5% on Cz-Si material (5.3% under back side illumination).

Keywords: Multi-Crystalline Silicon, Bifacial Solar Cell, Boron Back Surface Field

1 Introduction

Most of the common bifacial solar cells are made from silicon with very high charge carrier lifetimes, such as FZ silicon. They have a p/n junction on one side to separate the charge carriers [1]. These cell concepts are similar to a standard solar cell, except that they have an open rear side metallization which allows light to be collected on the rear side as well. We used this approach by replacing the standard Al BSF by boron BSF and an open rear contact. An overview of different bifacial cells is given in [2].
Another suitable concept for material with a lower diffusion length is a double sided shallow emitter structure. In this case the backside emitter is covered by a second additional finger grid [3], which leads to a higher shadowing of the backside. In our approach the emitter on the back side is connected via holes to the front side grid to avoid additional shadowing.
Also the power cell concept was used for bifacial cells [4]. Thinner wafers with a standard thick film aluminium paste for rear side metallization cause bowing of the wafer, leading to problems and breakage during later processing [5]. The solar cells presented here have an open rear contact and therefore have the advantage of avoiding bowing.

2 Solar cell process

2.1 Boron BSF bifacial solar cell

The cross-section of the boron BSF bifacial solar cell is shown schematically in Figure 1. The solar cell features an isotexture on both sides; the front side of the solar cell has a P-emitter from $POCl_3$ diffusion with 50 Ω/□ and PECVD SiN_x anti reflection coating. The rear side has a B-BSF, by BBr_3 diffusion and a SiO_2/ PECVD SiN_x stack system. The contact metallization was done by screen printing and co-firing in a belt furnace. In the experiments described below we used 125x125 mm² p-type mc Si wafers with a thickness of ~200 µm. The process of the solar cell is discussed in detail in [6].

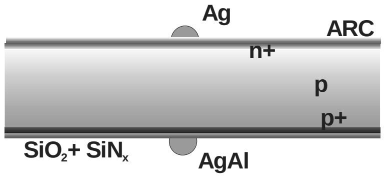

Figure 1: Cross-section of the boron BSF solar cell.

2.2 Double sided emitter bifacial solar cell

The second bifacial cell concept has a double sided emitter. On the back side the emitter region is separated from the region with the base contacts by a diffusion barrier which is printed to the wafer prior to phosphorus diffusion. Surface passivation and ARC was done using a LPCVD SiN_x. The emitters on both sides are connected via laser drilled holes (by a Nd:YaG laser), similar to the Emitter Wrap Through (EWT) solar cell [7]. The metal contact for the emitter is on the front side only; the backside is connected via the holes. For the front side metallization a Buried Contact (BC) designed was used. Not only the grooves are platted with Cu but also the holes which lead to a connection between the rear side emitters and the contact fingers on the front side; the holes are located directly under the grooves. The base is contacted on the rear side with a screen printed Ag/Al paste. The solar cell is shown schematically in Figure 2.

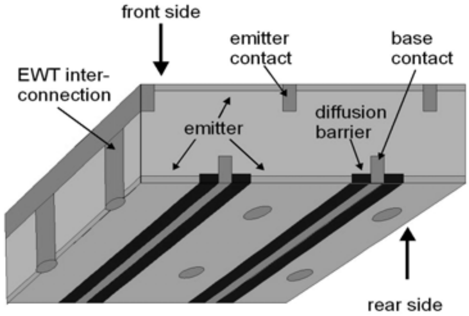

Figure 2: Schematic view of the bifacial solar cell.

In the experiments described below we used Cz-Si wafers sized 100 x 63 mm^2. First the saw damage was removed by NaOH etching followed by an industrial cleaning sequence. The diffusion barrier was printed on the back side to separate the emitter from the base. A shallow P-emitter ($POCl_3$, ~100 Ω/□) was diffused. For the surface passivation and ARC a LPCVD SiN_x was deposited on both sides with a thickness of 110 nm. Then the holes were processed with an Nd:YAG laser and the groves were made using a dicing saw. Correct alignment of the dicing and the firing of the holes with the diffusion barrier are important, otherwise the emitter contacts would be directly connected with the base. After an additional cleaning the wafers were heavily diffused (~10 Ω/□), only in the region where the SiN_x was removed. During the phosphor glass etch, the thickness of the AR coating was reduced to 70 nm. The base was contacted on the rear side by screen printed AgAl paste.

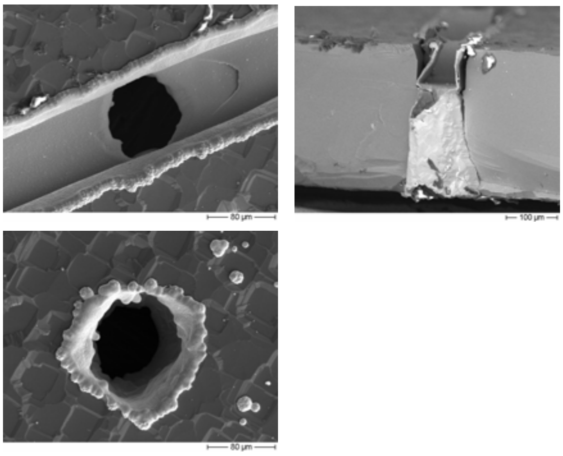

Figure 3: Electron microscopy pictures of the plated grooves and holes.

The emitter on the front side and the holes were contacted by Ni/Cu plating. The plating of the cells is depicted in Figure 3 showing the filling of the wholes with Ni/Cu. Finally the edges were cut for p/n junction isolation. The complete solar cell process is summarized in Figure 4.

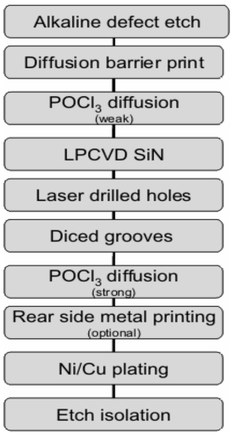

Figure 4: Process sequence of a double sided emitter solar cell.

3 Solar cell results

The best solar cell processed so far with a boron BSF (100x100 mm² p-type mc-Si wafer with a thickness of ~200 µm) had an efficiency of η=15.4% with J_{SC}=34 mA/cm², V_{OC}=614 mV and FF=73.9% [6]. Under back side illumination the performance (η=10.2 %, J_{SC}=22.6 mA/cm², V_{OC}=603 mV, FF=75.18 %) decreased as expected, due to the unfavourable ratio between wafer thickness and bulk lifetime (compared to FZ silicon) and a higher absorption for low wavelengths in the B-BSF [7?].
The cell with a double sided emitter (100x62 mm², p-type Cz Si, 300 µm thick) has an efficiency of η=11.5% with a J_{SC}=30 mA/cm², V_{OC}=587 mV and FF=65.5% and under back side illumination an efficiency of η=5.3% with a J_{SC}=13 mA/cm², V_{OC}=562 mV and FF=71.5%. The cell results of the best cells are summarised in Table I.

	FF [%]	J_{SC} [mA/cm^2]	V_{OC} [mV]	η [%]
Boron BSF + SiO_2 / SiN_x	**73.9**	**34.0**	**614**	**15.4**
back side illumination	**75.2**	**22.6**	**603**	**10.2**
Double sided Emitter	**65.5**	**30,0**	**587**	**11.5**
back side illumination	**71.5**	**13.1**	**562**	**5.3**

Table I: Solar cell results of best bifacial solar cells

4 Conclusions and outlook

The process for the mc-Si boron BSF bifacial solar cell leads to cell results which are comparable to industrial type solar cells and has in addition the benefit to collect the albedo on the rear. Due to the lower quality of the mc Si with short bulk lifetimes the performances of the boron BSF solar cell under back side illumination is decreased as expected. Minority carriers generated on the back side must travel through the whole wafer to reach the emitter. The cell with the double sided emitter collects the minority charge carriers from the nearest side of the cell, hence the minority carriers do not have to travel through the whole wafer to reach the emitter. Therefore the n^+pn^+ concept should be favorable for materials with low L_{eff}. However the performance of the n^+pn^+ cell is reduced compared to the performance of the B-BSF cell as the process is not optimized yet. The low FF and V_{OC} are limited by the LPCVD SiN_x surface passivation and a non optimized grid design. A surface texturing is not yet implemented in the solar cell process, therefore the light capture and the J_{SC} is lower. The boron BSF solar cell, also benefits from the hydrogenation from PECVD SiN_x. The shadowing on the back side is approx. 50% due the base contacts and the diffusion barrier. This limits J_{sc} and therefore the performance on the back side. Additional experiments with a smaller diffusion barrier led to shunts in the solar cell; the emitter was directly connected to the base grid. To reduce back side shadowing the replacement of the screen printed back contact by NiCu plating is planed.
The n^+pn^+ cell should be more applicable for materials with short bulk lifetimes, but the process presented here is more complicated, as the alignment of the diffusion barrier; the drilling of the holes and the contacts requires careful alignment and needs further optimization.

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