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Optimizing Screen Printed n-type Solar Cells Towards 20% Efficiency

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We present the status of our process development of silicon solar cells on n-type base material. Yingli Solar is manufacturing modules based on these cells, the Panda modules. We are constantly working on performance improvements, while maintaining low costs. In November 2011, we obtained a maximum solar cell conversion efficiency on n-type Cz at our ECN laboratory of 20.0% (239 cm^2) (in house measurement). To our knowledge this is the highest efficiency obtained so far with cell processing based on homogeneous emitter diffusion and screen-printed metallization. In this paper, we present an update of our cell process development, focusing on rear surface passivation.

N-type silicon solar cells

Currently, more than 85% of the solar modules produced worldwide are based on crystalline silicon, of which most are based on p-type wafers. Applying a phosphorous-diffused emitter and a aluminum back-surface field on a p-type wafer results in the common multi or mono crystalline solar cells used in the vast majority (95%) of wafer-based silicon PV modules [1]. The exceptions to this rule have been for many years the PV modules produced by Sanyo and Sunpower, who are using n-type wafers as base material for their high-efficiency cells: HIT (Heterojunction with Intrinsic Layers) cells in the case of Sanyo and IBC (Interdigitated Back Contacted) cells in the case of Sunpower [2,3]. For both cell types, efficiencies above 23% have been reported. Recently, Yingli Solar has also taken high-efficiency 'Panda' cells based on n-type wafers into production [4].

The use of n-type material has several advantages over the use of p-type. Firstly, there is no or very little boron dopant in n-type material and hence formation of boron-oxygen complexes will be negligible. B-O complexes are formed upon illumination in p-Cz material which is relatively rich in oxygen and degrade the bulk lifetime of the material. This severely limits the high efficiencies that can be obtained with these wafers [5,6]. Secondly, n-type material has been found to be much less sensitive to transition metal impurities such as, e.g., Fe [7]. This could give the n-type material a higher tolerance for variations in the feedstock [8].

Challenges for n-type solar cells

Manufacturing solar cells based on n-type material poses some additional challenges compared to the processing of solar cells on p-type material. One of them is the formation of a p-type boron emitter. Boron diffusion requires higher temperatures as compared to phosphorous emitter diffusions for p-type cells. This makes the simultaneous formation of emitter and BSF for n-type cells a challenge. In addition, the conventional method of passivating the emitter by silicon nitride (SiN_x) is less effective on p^+ boron emitter due to the positive fixed charges that are formed near the SiN_x/Si interface. These will cause a tendency towards depletion of the p^+ emitter; this will increase pn-product and consequently the effective surface recombination will increase. Nowadays however, there are several methods available to effectively passivate boron emitters. One of them that received a lot of attention in recent years is the application of an ALD (atomic layer deposition) Al_2O_3 layer which introduces fixed negative charges near/at the Al_2O_3/Si interface [9,10]. At ECN we have developed a simple wet chemical process followed by a PECVD deposition that forms a SiO_x/SiN_x passivation stack on the boron emitter [11,12].

Another concern for n-type cell processing may be the resistivity variation through an n-type ingot, which will be larger than for a p-type ingot due to the higher segregation coefficients for phosphorous. However, so far we did not see any adverse effects of the base resistivity on cell efficiency within the standard resistivity range (1 – 5 ohm-cm) of a commercially produced Cz ingot.

ECN's n-type concept: n-Pasha.

Figure 1 shows the basic configuration of the n-pasha solar cell. The cell has an open rear side, making it potentially suited as bifacial cell. This is a distinct difference with conventional p-type cells, adding to the efficiency gain when put into a module with a transparent rear side. Another way to profit from the bifacial cells is to put the cells in a module with a reflecting back sheet foil. Both front- and rear side feature H-grid metallization patterns in the n-pasha cells. The Panda cells Yingli Solar is manufacturing are made using this concept [4]. Furthermore, the cell concept can be easily adapted towards back contacted cells like Metal Wrap Through (MWT), as will be shown by Guillevin et al. in another contribution at this conference [13].

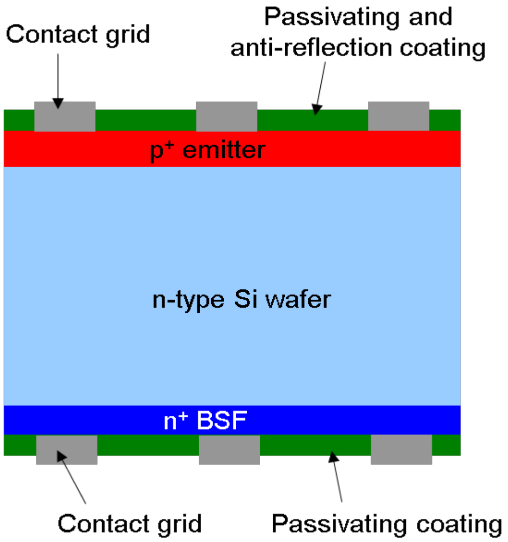

Figure 1. Cross section of the ECN n-pasha cell. Yingli's PANDA cells are also based on this cell configuration.

The n-pasha cells are fabricated on 6 inch semi-square n-type Cz wafers. The first processing step is to texture the wafers with random pyramids using alkaline etching. The boron emitter and phosphourous BSF are formed using an industrial tube furnace [14] from Tempress. A 60 ohm/sq emitter is made using BBr_3 as precursor. Both the front are rear side are coated with SiN_x layers for passivating and anti-reflective purposes. The metallization is applied on both front and rear side using screen printing, and the contacts on emitter and BSF are formed during a single cofiring step. Both front and rear metallization can be soldered directly so no additional metallization step is necessary to enable contacting into a module.

Improvements on n-pasha

The early stage of development of n-pasha solar cells was mainly concerned with the optimization of the front side: boron-diffusion and -passivation. Recently, focus has shifted to the rear of the n-pasha cell and optimizations on the phosphorous BSF and passivation have been made.

In figure 2, the implied V_{oc} values of cells (without metallization) with three different BSFs (different doping profiles) are shown. For the BSF with profile 3, a gain of over 15mV is observed over the standard BSF with profile 1. This voltage gain is also observed on cell level, although it is somewhat smaller: in six separate experimental runs, executed on n-type Cz material from 3 different suppliers, a gain of 8 to 10 mV has been observed for the improved BSF profile. The increase in V_{oc} can be explained by improved rear surface passivation. The difference in V_{oc} gain between cells with and without metallization can be explained by the contact recombination below the metal contacts. To optimize the rear surface further, obviously reducing the metal fraction is one of the options.

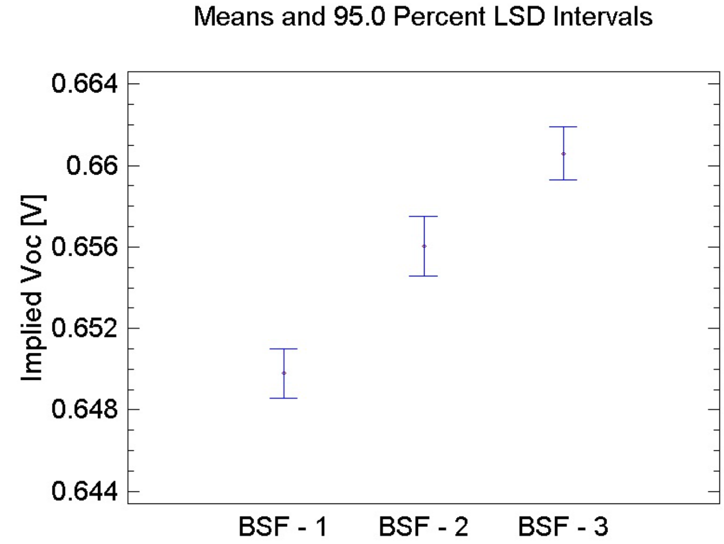

Figure 2: Implied Voc values for cells (without metallization) with 3 different BSF profiles.

Besides an increase in V_{oc}, also an increase in J_{sc} is observed for the improved BSFs. This is partly due to the improved rear surface passivation, but also due to increased internal reflection. In figure 3, J_{sc} and V_{oc} are shown . This graph shows the data of 3 different runs, executed on n-type Cz from different suppliers. For each run (distinguished by symbols) a standard group (blue symbols) and a groups with improved rear surface (red symbols) was processed. The gain in $J_{sc}*V_{oc}$ is around 3% relative, clearly reproduced for each run, and the gain is independent on the material quality range used in this experiments.

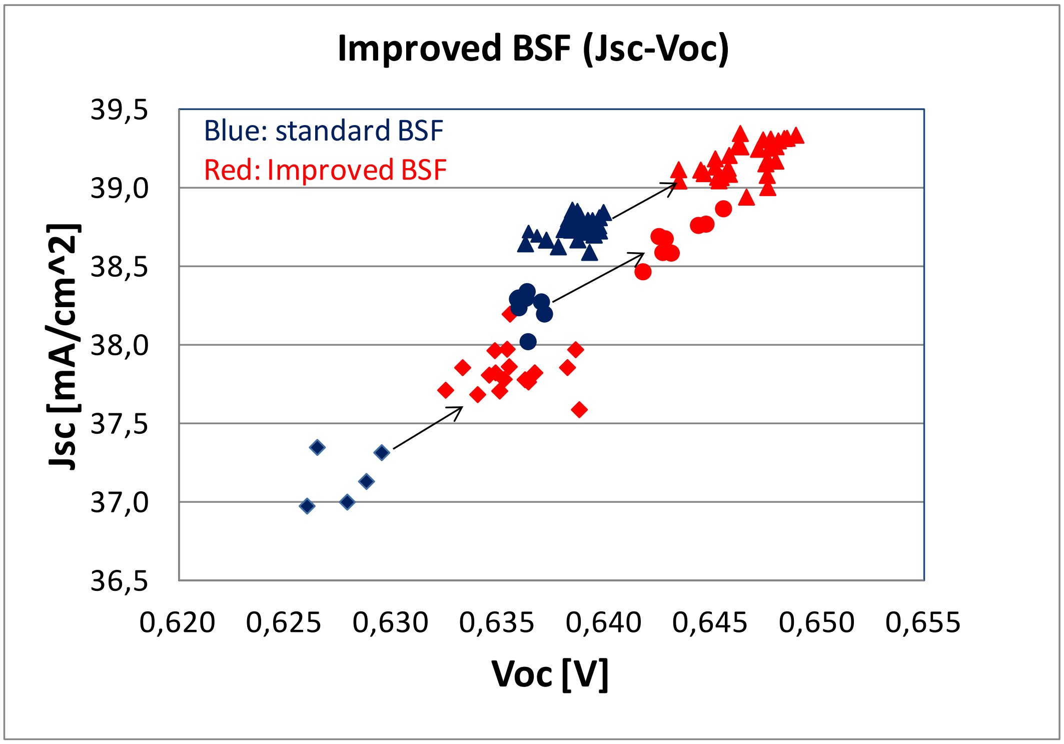

Figure 3: Gain in current and voltage observed in various runs using n-type Cz material of different suppliers. The collors depict the type of BSF, blue for standard BSF and red for the improved BSF. The symbols depict the various runs and materials used. The arrows are a guide to the eye, pointing at the gain within an experiment.

In table 1 and figure 4, the measurement results for one of the experiments aiming at improved rear surface passivation are shown. The improved rear surface passivation results in a significantly improved open circuit voltage (V_{oc}) and current (J_{sc}). Even though the fill factor (FF) is somewhat lower, an overall efficiency gain of 0.4% absolute is realized, and a highest efficiency of 20.0% has been reached (in-house measurement with a Class AAA solar simulator) .

TABLE I. IV results for a reference group and a group with improved rear surface1. Measurements were done in house using a Class AAA Solar simulator.

	I_{sc} [A]	J_{sc} [mA/cm2]	V_{oc} [V]	FF [-]	Eta [%]
Standard n-pasha (avg)	**9.26**	**38.7**	**0.640**	**0.784**	**19.4**
Max	**9.27**	**38.8**	**0.640**	**0.787**	**19.5**
Improved rear (avg)	**9.38**	**39.2**	**0.648**	**0.780**	**19.8**
Max	**9.40**	**39.3**	**0.649**	**0.783**	**20.0**

Since the cell is bifacial, the internal quantum efficiency (IQE) can be determined from both front- and rear side, as is shown in figure 4. The IQE graph from the front side shows that the long wavelength response has improved. This improvement is probably due to several causes: reduced rear surface recombination, improved rear internal reflection and reduced free carrier absorption. The IQE graph taken with rear side illumination shows that both the long- and short wavelength response has been improved. The large gain in blue response for the rear IQE is a clear indication of reduced rear surface recombination, while the gain in the red response can indicate a reduction in free carrier absorption.

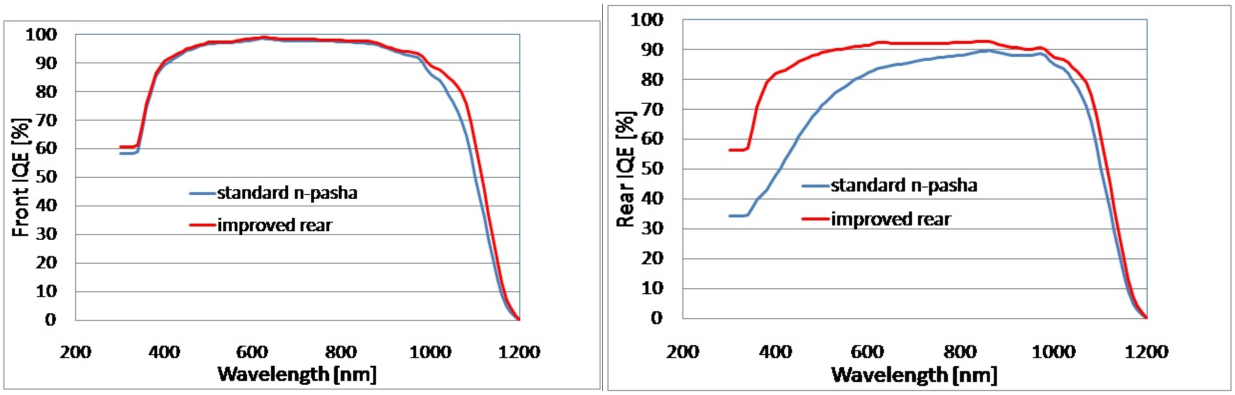

Figure 4: Left: Internal quantum efficiency measured from the front; Right: internal quantum efficiency measured from the rear. In both cases, the gain for cells with an improved rear surface is clear.

Summary

We have shown that the efficiency of n-pasha cells can be improved by 0.4% absolute in efficiency by improving the rear surface passivation. The process has been shown to give an increase in both J_{sc} and V_{oc} independently of the n-type base material quality range used in our experiments. This has enabled us to reach 20.0% on n-pasha cells, with industrial cell processes.

References

1. Photon International March 2009, p170 (2009)
2. Us.sunpowercorp.com.
3. www.sanyo.com/solar.
4. A.R. Burgers et al., 26th European Photovoltaic Soalr Energy Conference and Exhibition, Hamburg, Germany (2011).
5. J. Schmidt et al. 26th IEEE PVSC Anaheim, p13 (1997)
6. S. Glunz et al., 2nd WCPEC Vienna, p1343 (1998)
7. D. Macdonald and L.J. Geerligs, Appl Phys. Lett. **92**, p4061 (2008)
8. A. Cuevas et al., Appl Phys. Lett. **81**, p4952 (2002)
9. B. Hoex et al., Appl. Phys. Lett. **89**, p042112 (2006)
10. B. Hoex et al., Appl. Phys. Lett. **91**, p112107 (2007)
11. V. D. Mihailetchi et al., Appl Phys. Lett. 92, p63510, (2008), patent WO08039067
12. V. D. Mihailetchi et al., 22nd EPVSEC Milan, Italy, p837 (2007)
13. N. Guillevin et al., this conference
14. Y. Komatsu, Solar Energy Mat. & Solar Cells **93**, p750 (2009)