N-Type Multicrystalline Silicon Solar Cells: PERC Design for High Efficiency

J. Libal[1], R. Petres[1], R. Kopecek[1], G. Hahn[1], M. Vetter[2], I. Roever[3], K. Wambach[3], P. Fath[1]

[1]*University of Konstanz, Faculty of Sciences, Department of Physics, Jakob-Burckhardt-Str. 29, 78464 Konstanz, Germany, Phone (+49) 7531/88-3048; Fax (+49) 7531/88-3895; e-mail: Joris.Libal@uni-konstanz.de*
[2]*Universitat Politecnica de Catalunya, Dept. Enginyeria Electronica, C/ Jordi Girona 1-3, E-08034 Barcelona, Spain*
[3]*Deutsche Solar AG, Alfred-Lange Str. 18, 09599 Freiberg / Sachsen, Germany*

Abstract: In this report, high-efficiency solar cell concepts for n-type multicrystalline silicon (mc-Si) are presented. Cells with a totally diffused and metallised Back Surface Field (BSF) reached an efficiency of 15.1% with an antireflection coating. For a further improvement of the cell efficiency the application of the PERC [1] cell design on n-type mc-Si is proposed. First PERC cells have been processed and an efficiency of 10.2% has been obtained without antireflection coating. Optimisation of this process and application of a Double Layer Antireflection Coating (DLARC) is expected to lead to efficiencies exceeding 16%.

Key Words: n-type Si, mc-Si, solar cells, PERC

1 Introduction

There are two main motivations for using n-type Si for solar cell production: the first is the shortage of the Si feedstock. As there exists a similar quantity of n-type and p-type Si scrap from the electronic industry, making n-type Si available for solar cell production would attenuate significantly the shortage. In addition, some metallurgical-grade purification processes result more easily in n-type material than in p-type [2]. The second reason is that there is growing evidence that n-type mc-Si is superior to p-type mc-Si [3, 4], since it is less sensitive to certain metallic impurities [5]. This could result in solar cells with higher efficiencies if process steps are developed and optimised for n-type mc-Si. The development of a high efficiency solar cell process for n-type mc-Si is described here.

2 Experimental Results

2.1 Cells with P-diffused BSF

It has been shown that boron emitter diffusion with BBr_3 is possible while maintaining the high starting lifetime of the n-type mc-Si material [6] and obtaining an excellent response of the IQE in the short wavelength range [7].
Small laboratory solar cells ($A = 4$ cm^2) were made using the process depicted in Figure 1. Emitter diffusion was carried out using a BBr_3 dopant source with a subsequent thermal oxidation (an additional furnace step) and deglazing step for the removal of the boron-rich layer (BRL) that is created during boron diffusion. A BSF was formed by phosphorous ($POCl_3$) diffusion. The front grid was defined by photolithography and the contacts (Ti/Pd/Ag) on both sides were evaporated with a full rear contact. The parameters of the best solar cells resulting from this process are shown in Table I. The measured internal quantum efficiency (IQE) of the mc-cell from Table I shows an excellent response in the short wavelength range (Figure 2). In contrast to that, the long wavelength response can still be significantly improved.

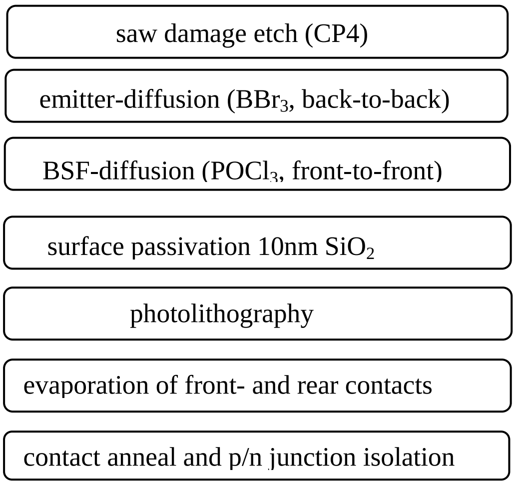


Figure 1 Solar cell process scheme

material	FF [%]	J_{SC} [mA/cm^2]	V_{OC} [mV]	η [%]
mc-Si (1 Ωcm)	78.6	23.3	603	11.0
Cz-Si (2 Ωcm)	77.9	24.4	604	11.5
	mc-cell with ARC		**Cz-cell with DARC**	
η [%]	**15.1**		**16.4**	

Table I Best solar cells made with with process shown in figure 1.

2.2 PERT and PERC solar cells

To improve the IQE for long wavelengths two conditions have to be fulfilled:

1.) the diffusion length in the bulk at the end of the cell process has to be as high as possible.
2.) the back surface recombination velocity has to be as low as possible.

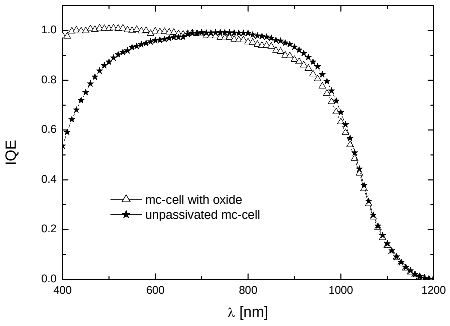


Figure 2 IQE of mc Si solar cells with passivated and unpassivated emitter.

The first condition is already met by a modification of the process in Figure I consisting in a BBr_3-diffusion (back-to-back) with an in-situ oxidation of the BRL (diffusion and oxidation in one furnace step) followed by a $POCl_3$-BSF diffusion (front-to-front) and the growth of a 10 nm SiO_2-layer for front surface passivation. Figure 3 shows the largely increased lifetime after the process which corresponds to a diffusion length of the minority charge carriers exceeding 500 µm.

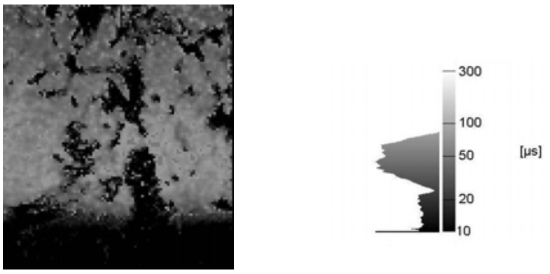
To meet the second condition, one can either perform a deep BSF-diffusion with $POCl_3$ (according to simulations with PC1D: at least 4 µm deep), a weak BSF-diffusion with SiO_2-passivation and local metal contacts (PERT design [9]) or no BSF-diffusion at all with the SiO_2-passivated n-type substrate and local metal contacts on the rear side (PERC design [1]). The deep $POCl_3$-diffusion requires a high thermal budget and could have a detrimental effect on the bulk lifetime and thus has been omitted. Cells with PERT-structure have been processed on n-type Cz material and showed a considerable increase of the IQE for long wavelengths resulting in an increase of J_{SC} by 6.5%. First PERC-cells have been processed on 1 Ohm·cm n-type mc-Si applying the process from Figure 1 without the $POCl_3$-diffusion and using point-contacts on the rear-side. The best cell reached an efficiency of 10.2% (without ARC), featuring a rather low fill factor of 70%, which is caused by the small front-grid fingers (15 x 3 μm^2) and possibly by a non optimized rear junction geometry.

3 Conclusions and Outlook

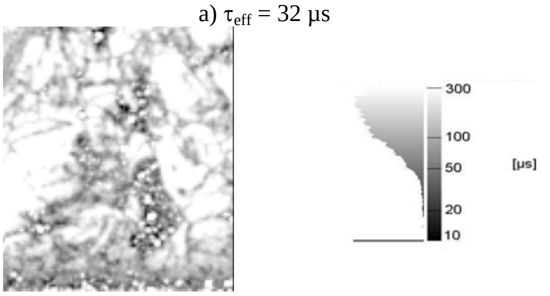
In contrast to the BSF-cells, the PERC cells are not P-gettered. Thus, to avoid a possible degradation of the bulk lifetime by the thermal oxidation of the PERC-cells, front surface passivation by PECVD SiC_x is examined (SiN_x passivates n^+-doped emitters of p-type cells, but depassivates the p^+-doped emitter of the n-type cells [8]).

Further improvement of the cell efficiency is expected from the use of 0.8 Ohm·cm Si (instead of 1 Ohm·cm) and an optimisation of the rear contact geometry. In addition Ag-plating will be used to obtain a good conductivity of the front finger-grid.

Considering the 11% efficiency which has already been achieved on flat cells with full metal contact on the rear side (i.e. a high rear surface recombination velocity), we expect efficiencies of 12% from PERC-cells without ARC and exceeding 16% with a DLARC (ZnS/MgF_2).



a) τ_{eff} = 32 µs



b) τ_{eff} = 214 µs

Figure 3 µW-PCD mappings of the bulk lifetime of a 10 x 12.5 cm^2 section of an n-type mc Si wafer (from the egde of the ingot): (a) before and (b) after cell process.
Diffused regions removed and surface passivated with iodine/ethanol-solution.

4 Acknowledgements

This work was supported within the NESSI project by the European Commission under contract number ENK6-CT2002-00660 and by the German BMU in the frame of the ASIS project (contract number 0329846J). The content of this publication is the responsibility of the authors.

5 References

[1] M.A. Green, J. Zhao, A. Wang, S.R. Wenham, *Very high efficiency silicon solar cells – science and technology*, IEEE Trans. El. Dev. 46 (10), 1940 (1999)

[2] R. Kopecek et al., Large *Area n-Type Multicrystalline Silicon Solar Cells with B-Emitter: Efficiencies exceeding 14%*, abstract submitted to this conference

[3] A. Cuevas et al., *N-type multicrystalline Silicon: a stable high lifetime material*, 3rd WCPEC, Osaka 2003

[4] R. Kopecek et al., *N-type multicrystalline material for solar cell processes with high effiency potential*, proc. of the 31st IEEE PVSC Orlando 2005 (in press)

[5] L.J. Geerligs and D. Macdonald, *Base doping and recombination activity of impurities in crystalline silicon solar cells*, Progress in Photovoltaics 12, 309 (2004); D. Macdonald and L.J. Geerligs, proc. of the 19th EU PVSEC Paris 2004, 492

[6] J. Libal et al., *Properties of n-type multicrystalline silicon: lifetime, gettering and H-passivation*, proceedings of the 19th EU PVSEC Paris 2004, 1013

[7] J. Libal et al, *n-type multicrystalline silicon solar cells with BBr_3 diffused front junction*, proc. of the 31st IEEE PVSC Orlando 2005 (in press)

[8] R. Petres et al., *Passivation of P^+-Surfaces by PECVD Silicon Carbide for Industrial Silicon Solar Cell Applications*, abstract submitted to this conference

[9] A.W. Blakers et al., *22.8% efficient silicon solar cell*, Appl. Phys. Lett. 55 (13), 1989, 1363