Different Aspects of Back-Surface Field (BSF) Formation for Thin Multi-crystalline Silicon Wafers

A. Kränzl, A. Schneider, I. Melnyk, A. Hauser,
E. Rüland and P. Fath

University of Konstanz (UKN), Faculty of Physics,
P.O.Box X916, D-78457 Konstanz, Germany
Tel.: +49-7531-88-3174, Fax: +49-7531-88-3895
E-mail: andreas.kraenzl@uni-konstanz.de

(Received : 31 January 2004 – Accepted : 15 March 2004)

Abstract : The standard industrial process for manufacturing multi-crystalline silicon solar cells includes a screen printed aluminium-BSF, achieving an average efficiency of more than 15 % in industrial production. One key issue for reducing costs of photovoltaic devices is the use of thinner wafers. In existing production lines the average wafer thickness is about 300 µm, but with advances in wafer technology thinner wafers of 200 µm thickness and less are available. Thinner wafers with a standard thick film aluminium paste for rear side metallization cause bowing of the wafer, leading to problems during later module manufacturing [1].

Alternative methods for rear side passivation and contacting schemes such as boron BSF formation, silicon oxide or silicon nitride passivation have not yet achieved the same performance as the aluminium BSF. An additional benefit of the fully covered aluminium rear side is the assistance of hydrogen diffusion into the bulk with PECVD SiN.

Introduction

In this work we studied the performance of thin multi-crystalline Baysix wafers sized 12.5 x 12.5 cm² and thicknesses below 250 µm with different types of BSF formation. For the wafer processing we applied the UKN standard process (saw damage etch, $POCl_3$- diffusion, phosphorus glass etch, edge isolation, PECVD SiN_x, screen printing metallization and co firing) with modifications of the backside metallization due to the thin wafers, aiming at lower bowing of the cells.

Results and Discussion

First the amount of aluminium paste printed on the back side of the wafer was reduced by the use of different screens with different mesh counts and respectively different screen openings. We investigated different compositions of Al pastes called A and B (Each group consists of five wafers). We found a correlation of bow, paste thickness and paste composition. The right Al-paste composition and screen properties lead to a wafer bending below 1 mm. The current and performances of the cell was unfortunately also reduced (Table I). The amount of Al paste on the wafer was weighed after printing and drying of the pastes. Efforts to further reduce the amount of paste and use finer screens didn't lead to reproduceable result so far.

Table 1. Solar cell results on mc-Si wafers (156 cm^2).

Al [mg/cm^3]	Al paste	V_{OC} [mV]	J_{SC} [mA/cm^2]	FF [%]	ETA [%]	Bow [mm]
7.3	A	616	32.0	78.0	15.4	1.32
5.5	A	614	31.6	78.1	15.2	0.91
7.2	B	614	31.8	77.8	15.2	0.97
5.8	B	614	31.6	77.5	15.1	0.71

For a more comprehensive understanding of the results Electrochemical Capacitance Voltage (ECV) [2] measurements were carried out. Two samples were prepared with different amount of Al-paste (A) printed. Both samples were fired for the same time at the same peak temperature. Before the ECV measurement the Al paste was etched off. In Fig. 1 the carrier concentration is plotted versus the depth into the wafer. The carrier concentration measured with ECV is an average over an area of 9 mm^2.

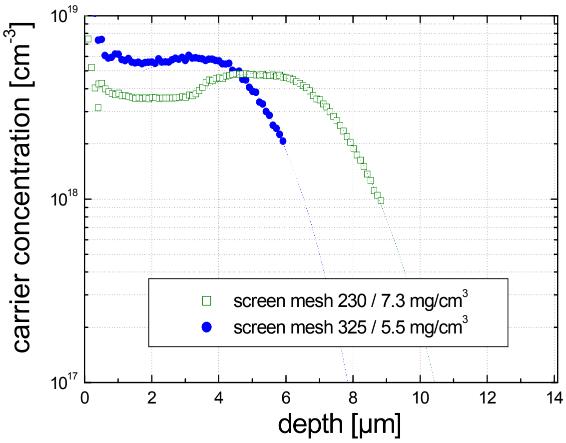

Figure 1. ECV measurements on wafers with different BSF, the carrier concentration is plotted versus the depth into the wafer.

The first points in the ECV measurement could be influenced by Al residues on the wafer or other surface effects. Near to that there is a plateau with an almost constant carrier concentration reaching up to 6 µm into the wafer. This plateau of the carrier concentration is expected to be on the same level for both samples. We ascribe the deviation in the plateau levels to inaccuracies in the ECV measurement.

However there is a tendency, if more Al is printed on the rear side the plateau reaches deeper into the wafer. This indicates that the higher amount of printed Al paste leads to a deeper BSF field. The deeper BSF is in correlation with the better cell performance for the solar cells with more Al printed on the back side.

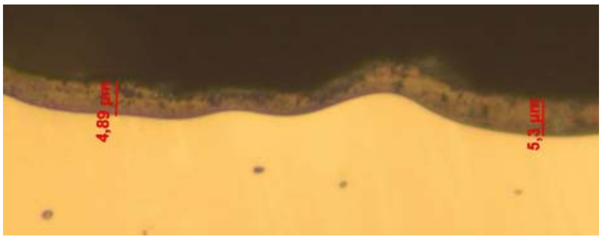

Figure 2. Cross section of a Si wafer with a Si-Al eutectic layer.

In Fig. 2 the cross section through a Si wafer is shown. The Al-Si eutectic interface was coloured using a selective defect etch. The interface of the eutectic layer with the bulk Si is not flat but ondulated. Also the thickness of the Al-Si layer varies between 4-6 µm. Variations in the BSF thickness can also influence ECV measurements, depending on the position on the sample.

The amount of paste could also be reduced with modified rear side printing screens Fig. 3. Also the area printed on the wafer is reduced. The aluminium paste was printed in groups by 4 × 4 and 7 × 7 squares connected with small bridges.

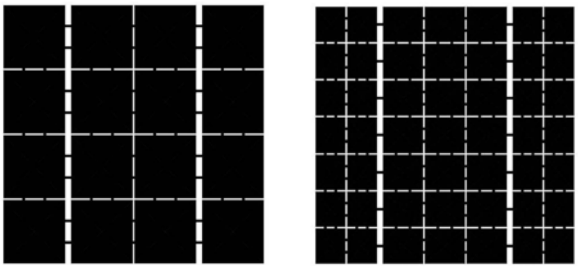

Figure 3. Screen designs with 4×4 squares and 7×7 squares.

A standard aluminium paste was used in order to measure the effect on the cell bending of smaller contiguous aluminium areas. Cell performance and bow were compared to standard solar cells with Al-paste printed all over the backside. The measured reduction of the bow was mainly due to the smaller amount of aluminium paste and print area.

Table 2. Solar cell results on mc-Si wafers (156 cm^2).

Covered area [%]	Avg. bow [mm]	Avg. bow reduction [%]	Avg. ETA [%]
100	3.45	0	15.2
95 (4×4 Sq.)	3.29	4.7	15.2
92 (7×7 Sq.)	3.09	10.5	15.1

Voltage and Current are decreasing with less area covered, which leads to a slight loss of performance (Table II).

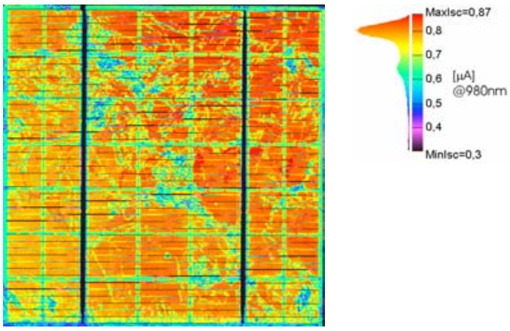

Figure 4. LBIC measurement (wavelength of 980 nm) of a 12.5×12.5 cm^2 solar cell with Al BSF printed with a 7×7 square pattern.

The increased carrier recombination can also be seen in the laser beam induced current (LBIC) measurement in Fig. 4, with a long laser wavelength (980 nm).

For another approach the acidic etching [3] was utilised to remove the saw damage and texture the multi-crystalline wafer simultaneously. The isotropic etch solution consists of HF and HNO_3 in addition to water. The advantage of the UKN-Isotexturing method for thinner wafers is an etch depth of only 5 µm per side from the as-cut wafer. The UKN-Isotexturing leads to a reduction of reflection and therefore improvement of cell performance. As on standard 350 µm thick wafers there is an increase in cell performance and J_{sc}.

Using optimised Al paste compositions cell efficiencies up to 15.9 % were reached on 200 µm thin Baysix wafer. The average efficiency over 12 cells was 15.7 % with an average bow less than 0.9 mm (Table III). These are the highest cell efficiencies we reached so far for thin, screen printed mc-Si solar cells.

Compared to standard NaOH etched cells (Table I) there is an increase in cell efficiency up to 0.5 % absolute. J_{sc} is higher and V_{oc} is lower due to the larger surface area of the textured wafers.

We claim the following effects responsible for the lower bow (compared to wafers with an alkaline etch), the etch depth of only 5 µm per side from the as-cut wafer, the texturing of the surface and the lower peak temperature at the co-firing step after the metallization.

Table 3. Solar cell results on mc-Si wafers (156 cm^2).

	J_{SC} [mA/cm^2]	V_{OC} [mV]	FF [%]	ETA [%]
texture best cell	33.2	611	78.5	15.9
texture average	33.1	612	78	15.8

Conclusions

There is a correlation between the amount of Al printed on the back side, the thickness of the BSF and cell performance.

It has been shown that the reduction of the area covered (5% and 8%) with Al paste by screen printing to the backside reduces the bowing of thin wafers in average around 10%. However the solar cell performance is only slightly reduced (Table II).

The texturing of the solar cells lead to a reduction of the reflection therefore an improvement of cell performance and also the bowing is reduced. Further investigation have show if there is an additional benefit in reducing the printed Al paste on the backside of textured wafers.

Additionally to previous results [1] these experiments show the potentialities of thick-film metallization applied on

200 µm-thin wafers, processing solar cells with low wafer bending and without loss of performance.

Acknowledgement

We would like to thank N. Gawehns for her support in cell processing. The help of R. Kopecek for the ECV measurements is also gratefully acknowledged.

References

[1] Schneider, A. (2001) Al BSF for Thin Screen-printed Multicrystalline Si Solar Cells, *17th EPVSC 2001*, Munich, Germany.

[2] Peiner E. (1985) Doping Profile Analysis in Si by Electrochemical Capacitance-Voltage Measurements, *J. Electrochem. Soc.,* **142**.

[3] Hauser, A. (2003) A Simplified Process for Isotropic Texturing of mc-Si, *3rd WCPEC*, Osaka, Japan.