COMPARISON OF THE PASSIVATION QUALITY OF BORON AND ALUMINUM BSF FOR WAFERS OF VARYING THICKNESS

Stefanie Riegel, Sebastian Gloger, Bernd Raabe, Giso Hahn
University of Konstanz, Department of Physics, Jacob-Burckhardt-Str. 29, 78457 Konstanz, Germany
Email: Stefanie.Riegel@uni-konstanz.de, Phone: +49 7531 88 2074, Fax: +49 7531 88 3895

ABSTRACT: The aim of the work is the comparison of large area Cz-Si solar cells with boron back surface field (B-BSF) to those with full area aluminum (Al) BSF. The investigations are carried out with respect to the influence of the wafer thickness on the cell performance. Boron doped Cz-Si wafers of varying thickness (115-240 µm) are used as bulk material. The B-BSF is formed by BBr_3-diffusion. Metallization is applied via screen printing a grid on the front and rear side. Full area aluminum BSF solar cells are used as reference. The solar cells show high open-circuit voltages (V_{OC}) up to 635.4 mV and short-circuit current densities (J_{SC}) up to 36.5 mA/cm^2. Neither V_{OC} nor J_{SC} decrease with decreasing wafer thickness. The full area Al-BSF reference solar cells show decreasing fill factors and therefore reduced cell efficiencies with decreasing wafer thickness. The cells with B-BSF reveal internal quantum efficiencies (IQEs) of 60% at 1100 nm. Going to thinner wafers, the IQE is not reduced in the long wavelength regime. The effective back surface recombination velocities (SRVs) extracted from a physical model fitted to spectral response measurements are in the range of 80-200 cm/s for the boron BSF cells. Effective back SRVs of the aluminum BSF cells are determined to 260-700 cm/s.
Keywords: boron back surface field, wafer thickness, passivation

1 INTRODUCTION

Costs for crystalline silicon wafers are a significant part of the costs of solar cells. One approach to reduce costs for solar cells is to decrease costs for silicon wafers. This can be done by using low cost and therefore lower quality material or by reducing wafer thickness.

When applied to thin wafers with thicknesses below 150 µm, the widely used screen printing process causes problems due to the full area metallization of the rear side (wafer bow and recombination at the rear side). This can be avoided by forming the back surface field (BSF) via borontribromide (BBr_3) diffusion. Additionally we assume higher open circuit voltages as the BBr_3 diffused B-BSF is higher p-doped than an Al-BSF fabricated by screen printing and firing [1, 2]. The diffused B-BSF is significantly thinner than the Al-BSF [1, 2]. Therefore, the minority charge carrier diffusion length inside the B-BSF can be large compared to the B-BSF thickness. If this is the case, the effective rear SRV can be reduced by an additional dielectric passivation layer in contrast to an industrial-type Al-BSF where additional passivation shows no significant effect [3].

Furthermore, the rear metallization of the B-BSF solar cells is formed by a fingergrid. This allows for (additional) illumination from the rear side of the solar cells.

2 SOLAR CELL PROCESS

Bifacial silicon solar cells with B-BSF are processed from 125x125 mm^2 p-type Cz-Si wafers (1.5 Ωcm) of varying thickness in the range from 115 to 225 µm. The process scheme is shown in Figure 1. After damage etching the B-BSF is formed by BBr_3 diffusion in a tube furnace. After the removal of the boron glass a thin thermal oxide and PECVD silicon nitride are deposited on the rear side to passivate the surface and to protect it during the following process steps. Then the boron diffused front side is etched off in hot NaOH. Front sides are treated with random pyramid texture followed by $POCl_3$ emitter diffusion and PECVD SiN_x antireflection coating (ARC). Metallization is done by screen printing a finger grid using silver paste on the front and silver/aluminum paste on the rear side. Edge isolation is performed by sawing 2 mm from each wafer edge, the final cell size is 121x121 mm². The processing of the cells with Al-BSF starts with random pyramid texturing. Cell processing is carried out in parallel to the processing of the B-BSF cells except for the metallization. The cells with aluminum BSF have a completely metallized rear surface.

As the B-BSF process includes two more etching steps than the Al-BSF reference process (see Figure 1), the wafers that underwent the B-BSF cell process are 10-15 µm thinner than the wafers processed with the Al-BSF reference process.

Cells are characterized with illuminated-voltage (IV) and spectral response (SR) measurements.

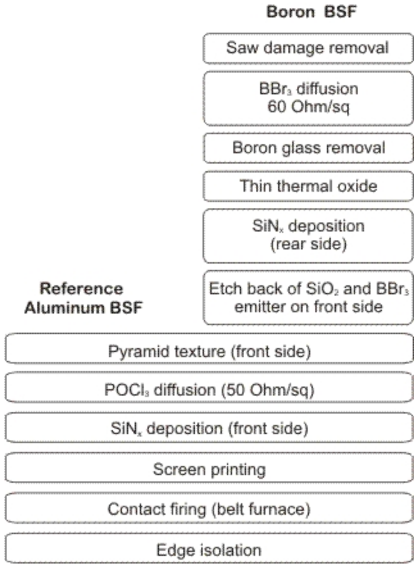

Figure 1: Process scheme for boron BSF (right) and aluminum BSF (left) process.

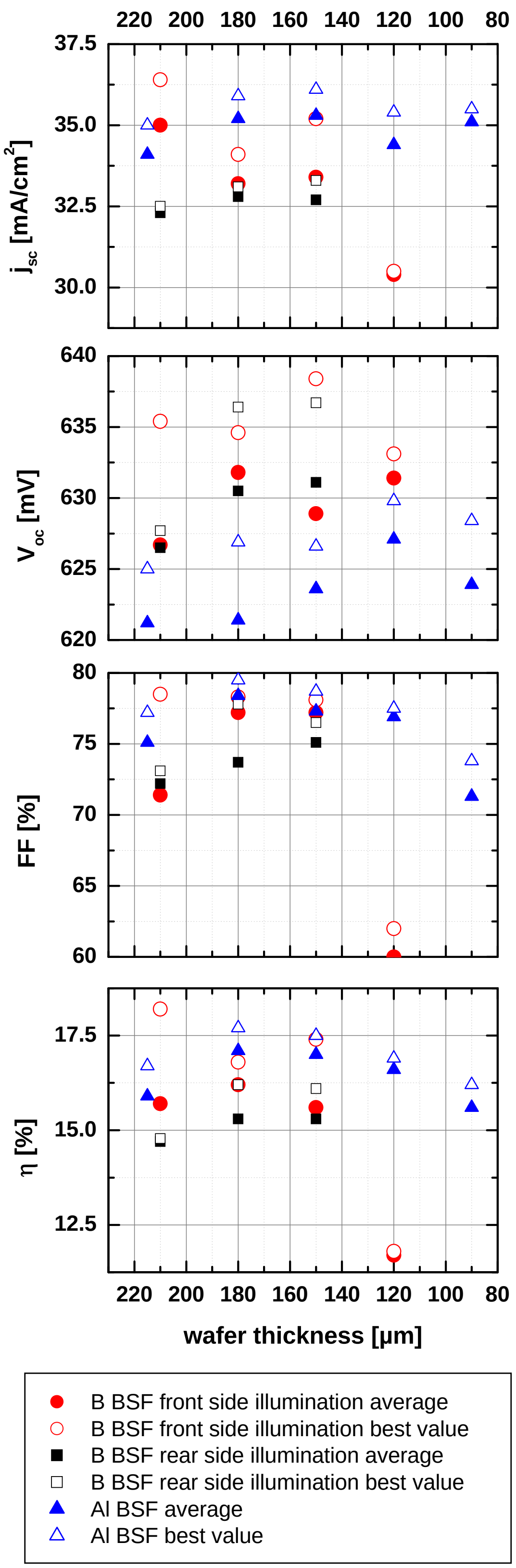

Figure 2: IV data of the solar cells. Solar cells with boron BSF are measured under front as well as under rear side illumination. All solar cells are measured on a brazen chuck (~90% reflectivity).

3 EXPERIMENTAL RESULTS

3.1 IV-measurements

All solar cells are measured on a brazen chuck. As the B-BSF solar cells are bifacial, light can enter the solar cells from the rear side as well. Long wavelength light transmitting the solar cell is reflected by the chuck. Therefore, the cell is measured under some kind of bifacial illumination. The chuck reflectivity is ~90% in the long wavelength regime (> 85% for λ>750 nm, >90% for λ>900 nm). The results of illuminated-voltage measurements of the solar cells are shown in Figure 2. The BBr_3 diffused screen printed cells show high open-circuit voltages (V_{OC}) up to 638.4 mV and short-circuit current densities (J_{SC}) up to 36.5 mA/cm². The mean value $J_{SC,\,mean}$=33-35 mA/cm² is rather low. This is caused by a not optimum front surface texturing (for reflection curves see Figure 3). Neither FF nor V_{OC} nor J_{SC} decrease with decreasing wafer thickness down to 160 µm. Under rear illumination the boron BSF cells still show a high V_{OC} up to 633.4 mV. J_{SC} under rear side illumination is reduced compared to front side illumination because the rear surface is not textured. Unfortunately, the fill factors of the 130 µm cells are extremely reduced, we assume a mechanical problem, e.g. cracks.

The Al-BSF solar cells of the 215 µm and the 110 µm group show reduced fill factors and efficiencies due to the non optimized firing conditions which could not be adapted properly in this experiment. The Al-BSF cells show stable V_{OC} and J_{SC} values for wafer thickness down to 110 µm. Maximum values are lower than the values we achieve with B-BSF: $V_{OC,max}$=629.8 mV and $J_{SC,max}$=36.1 mA/cm. The solar cells show a loss in fillfactor of $1.5\%_{abs}$ from 190 µm to 140 µm (78.4% to 76.1%).

3.2 Spectral response measurements

Spectral response and reflectivity measurements are also performed on a brazen chuck. To extract the effective surface recombination velocity (SRV) from the measured internal quantum efficiency (IQE) curves, an IQE evaluation program from B. Fischer [3] based on models from P. A. Basore [4] and R. Brendel [5] is used. The SRVs are extracted in the wavelength regime from 850 to 950 nm for all solar cells. To fit the bifacial B-BSF solar cells, one needs to pay attention to the physical meaning of the optical parameters (with x: Lambertian, y: direct R_{back}, a: texture angle). The parameter set does not describe the optical properties of the solar cells but the optical properties of the solar cells *including the chuck.* If the solar cells are measured on another chuck, the optical parameter set changes.

Because of the reduced cell performance, the 215 µm and 110 µm B-BSF cells are not measured. The B-BSF cells of 130, 160 and 180 µm thickness show IQEs of more than 60% at 1100 nm (see Figures 3, 4). Going to thinner wafers, the IQE is not reduced in the long wavelength regime (see Figure 3). Below 700 nm the 160 µm and the 130 µm cell show a slightly reduced IQE compared with the 180 µm cell. The effective back surface recombination velocities extracted from spectral response measurements are in the range of 80 to 200 cm/s, depending on the assumptions concerning the reflectivity fitting ($0.9 < y < 0.92$, $0.64 < x < 0.74$,

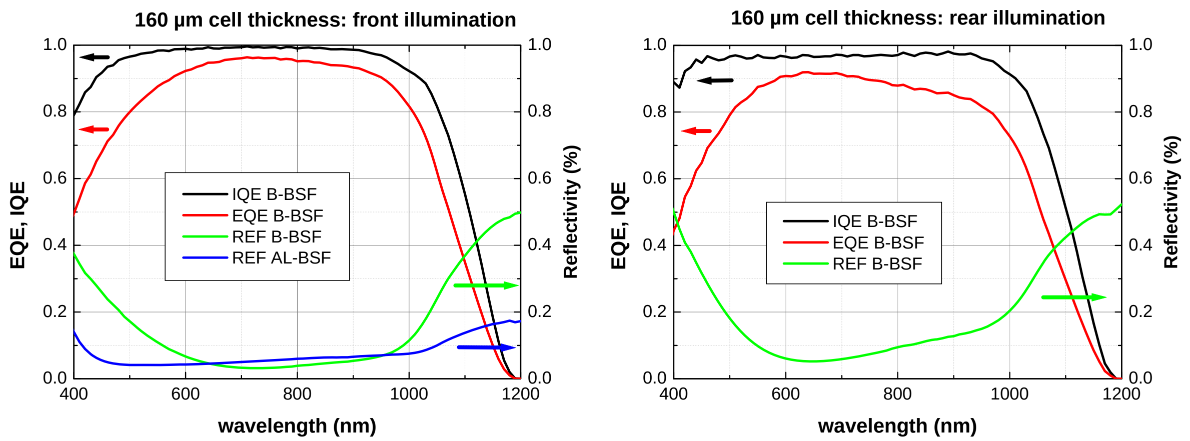

Figure 3: Spectral response measurement of the 160 µm bifacial solar cells with B BSF. Data is taken under front (left) and rear (right) side illumination on a brazen chuck (~90% reflectivity). The cell shows an IQE of 60% at 1100 nm. The nearly horizontal characteristics under rear side illumination in the wavelength regime up to 900 nm indicates a high effective diffusion length (see text). The left graph includes the reflectance of an Al BSF solar cell for comparison.

$0.58 < \cos\alpha < 0.78$, with x: Lambertian, y: direct R_{back}, α: texture angle).

The IQE of bifacial solar cells under rear side illumination typically has a maximum in the long wavelength regime and a lower plateau in the range of 500 to 900 nm [6]. The IQE of the solar cell shown here does not show a significant decrease going from the long to the medium wavelength regime (see Figure 3). This behavior is due to excellently low surface recombination velocities on the front and rear. Because rear surfaces are not textured, they show a higher reflectance than front surfaces. Additionally, the SiN_x layer deposited on the rear surface is thicker than on the front surface. A textured rear surface would improve short-circuit currents under rear illumination.

In contrast to the B-BSF solar cells, the full area Al-BSF solar cells do not transmit the light to the brazen chuck, since the light is absorbed in the aluminum layer. In addition the passivation quality is worse than for the B-BSF cells. Therefore, the IQEs of the Al-BSF cells are reduced for wavelengths above 1000 nm compared to the ones of the bifacial B-BSF cells (see Figure 4). The effective back surface recombination velocities extracted from spectral response measurements vary from 260 to 700 cm/s. A correlation with wafer thickness is not found. The optical parameters used for the fitting procedure are: $0.6 < y < 0.7$, $0.91 < x < 0.97$, $0.55 < \cos\alpha < 0.93$, with x: Lambertian, y: direct R_{back}, α: texture angle. These SRV values are significantly higher than the ones extracted for the B-BSF solar cells. This indicates that the surface passivation provided by the Al-BSF is less effective than the one provided via B-BSF in combination with a SiO_2/SiN_X stack. The optimum B-BSF doping density and SiO_2 thickness in combination with the covering SiN_X layer for bifacial B-BSF cells was investigated elsewhere [7].

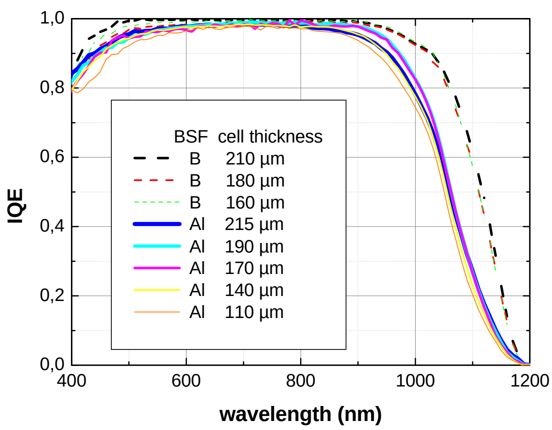

Figure 4: Spectral response measurement of solar cells with B-BSF and Al-BSF, respectively. Data is taken with front side illumination on a brazen chuck (~90% reflectivity). For wavelengths above 1000 nm the IQE of the bifacial B-BSF cells is increased as they collect light transmitting the cell and being reflected by the chuck. In the regime from 850 to 950 nm the influence of the passivation is visible (see text).

4 CONCLUSION

It is possible to maintain stable FF, V_{OC} and J_{SC} on thin wafers (demonstrated down to 160 µm) using a screen printed solar cell process including B-BSF on Cz-Si solar cells. For Al-BSF solar cells, we observe a decrease in fill factors with decreasing wafer thickness, most probably due to non optimized firing conditions, and stable V_{OC} and J_{SC} for wafer thicknesses down to 110 µm. Spectral response measurements show that a good passivation of the rear surface via B-BSF is possible. The solar cells with B-BSF show IQEs of 60% at 1100 nm. Going to thinner wafers, the IQE is not reduced in the long wavelength regime. The effective back SRVs extracted from spectral response measurements are in the range of 80 to 200 cm/s for the

B-BSF solar cells. Effective back SRVs of the Al-BSF solar cells are 260 to 700 cm/s.

For further improvements in solar cell performance, especially in J_{SC}, the front texture should be improved. The saw damage from the B-BSF solar cells is removed to reduce recombination centers at the rear surface. Hence, the saw damage can not serve as a starting point for the texture.

5 ACKNOWLEDGEMENTS

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