INVESTIGATION OF THE BACK SIDE PASSIVATION LAYER OF SCREEN PRINTED BIFACIAL SILICON SOLAR CELLS

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ABSTRACT: This work compares the back side passivation quality of bifacial silicon (Si) solar cells with boron back-surface-field (B-BSF) of different sheet resistances. The influence of the thickness of an additional dry thermal silicon dioxide (SiO_2) to passivate the surface of the B-BSF is also investigated. The passivation quality is compared in two experiments: First Si lifetime samples with boron (B) emitter are passivated and their emitter saturation current densities (J_{0E}) are determined with quasi-steady-state photoconductance (QSSPC) measurements after every process step. Secondly large area bifacial solar cells with different base doping are processed. The cell parameters are determined by illuminated current-voltage (IV) characteristics and the effective minority charge carrier diffusion lengths (L_{eff}) are calculated with a model [1] using the internal quantum efficiencies (IQE) from spectral response measurements. The optimum B-BSF sheet resistance for the bifacial cell concept used is found to be 60 Ohm/sq. The optimum value of the thickness of the SiO_2 layer for additional surface passivation is found to be in the range of 19-30 nm dependent on the base doping.

Keywords: passivation, back-surface-field, bifacial

1 INTRODUCTION

The widely used screen printing solar cell process causes problems like recombination at the back side (BS) and wafer bow, especially when applied to thin wafers. To avoid the problems of the full area metallization of the BS a B-BSF and a finger grid can be used, allowing also illumination of the solar cell from the BS. Theoretical calculations predict that the passivation quality of a BSF is determined by its doping depth and density as well as by the base doping, the carrier mobilities and diffusion lengths [2]. To examine the interrelation between the passivation quality and the doping profile experimentally, we process symmetrical lifetime samples and bifacial solar cells with different B-BSF doping profiles. As it is known, that silicon nitride (SiN_X) is not suitable for the passivation of contacted p^+-Si surfaces [3], we use SiO_2/SiN_X stacks for back side passivation. We investigate the influence of the thickness of the SiO_2 layer on the passivation quality.

2 LIFETIME SAMPLES

To determine the passivation quality of different B-BSF doping profiles, emitter saturation currents are measured with the QSSPC technique on float-zone (FZ) Si wafers. Therefore, phosphorous doped n-type wafers with a size of 50^2 mm², a thickness of 550 µm and a resistivity R_{Bulk} of 1 Ohmcm are symmetrically processed using the following steps:

A boron emitter is created by a borontribromide (BBr_3) diffusion. This p^+-emitter has a sheet resistance R_S of 34, 60 or 82 Ohm/sq and a thickness of 0.4-0.9 µm dependent on R_S. The boron glass is removed in a diluted hydrogen fluoride (HF) solution. For additional passivation a thermal oxidation is carried out. The thickness of the SiO_2 layer is 23-26 nm. As antireflection coating and hydrogen source a plasma-enhanced chemical vapor deposited (PECVD) hydrogen rich silicon nitride (SiN_X:H) layer with a thickness of ~ 100 nm is deposited on both wafer sides (see figure 1). To determine the influence of the thermal impact of a phosphoryl chloride ($POCl_3$) diffusion in a solar cell process the samples are subjected to a high temperature step with the temperature and duration typical for a $POCl_3$ diffusion.

QSSPC measurements are performed on samples of all three sheet resistances after emitter diffusion, after thermal oxidation, after SiN_X:H layer deposition without firing and after the high temperature step simulating a $POCl_3$ diffusion. The values for J_{0E} are determined in high injection [4].

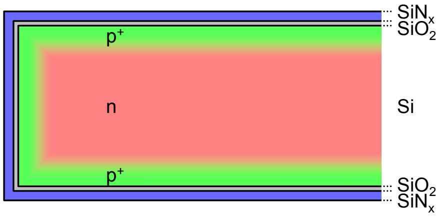

Figure 1: Passivated n-type silicon sample with B-emitter, SiO_2 and SiN_X:H layer.

3 EXPERIMENTAL RESULTS: SAMPLES

The J_{0E} values obtained from QSSPC measurements are shown in figure 2. Directly after BBr_3 diffusion the J_{0E} mean values for the different diffusions are in the range from 4800 to 17000 fA/cm². The thermal oxidation reduces J_{0E} to mean values from 1600 to 2100 fA/cm². After the PECVD SiN_X:H deposition the J_{0E} mean values are in the range from 300 to 900 fA/cm² this means passivation with a SiO_2 layer is improved by the PECVD SiN_X:H deposition. The following high temperature step with the temperature and duration typical for a $POCl_3$ diffusion increases J_{0E} due to a loss of hydrogen at the Si/SiO_2 interface to mean values from 600 to 1100 fA/cm². After every process step the 60 Ohm/sq diffusion obtained the lowest mean J_{0E} and the 34 Ohm/sq diffusion the highest. The best passivation is achieved with a B-emitter doping of 60 Ohm/sq and a SiO_2/SiN_X:H stack. This combination leads on the best sample to a J_{0E} of 280 fA/cm².

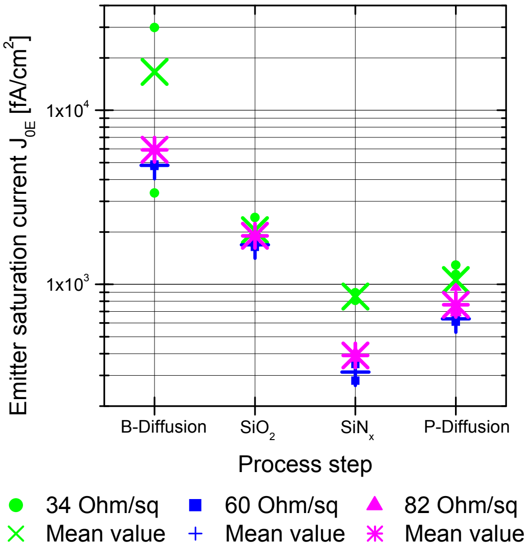

Figure 2: J_{0E} values of the lifetime samples after a BBr_3 diffusion, a thermal oxidation, PECVD SiN_X:H deposition and a high temperature step typical for a $POCl_3$ diffusion.

4 BIFACIAL SILICON SOLAR CELLS

To determine the quality of the back side passivation we produce bifacial solar cells with different B-BSF doping profiles (R_S: 10, 34, 60, 82 Ohm/sq) and SiO_2 layers of different thickness (18-54 nm). The IV characteristics and IQEs of the cells are measured and the corresponding L_{eff} is extracted using the model of B. Fischer [1].

The solar cells are processed based on B-doped p-type Czochralski (Cz) Si wafers with a size of 125^2 mm^2 semisquare, a thickness of 220-250 µm and a R_{Bulk} of 1-5 Ohmcm. First the back side is doped with a p$^+$-B-BSF with a R_S of 10, 34, 60 or 82 Ohm/sq and in the following passivated by a thermal oxide of 18-54 nm and a PECVD SiN_X:H deposition. Subsequent the front side is processed with a random pyramid texture, a standard $POCl_3$ emitter a PECVD SiN_X:H and a screen printed Ag grid. The back side metallization is formed by screen printing an Ag/Al finger grid (see figure 3 and figure 4).

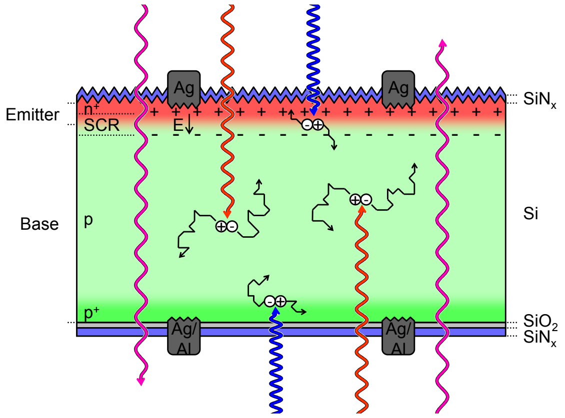

Figure 3: Screen printed bifacial solar cell concept.

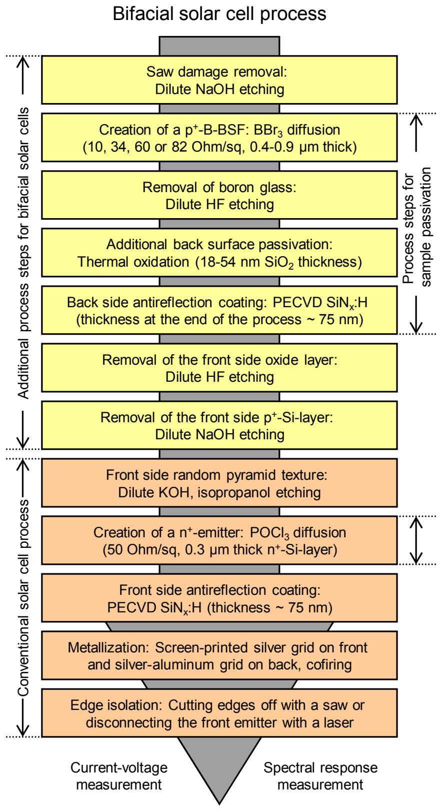

Figure 4: Bifacial solar cell process.

5 EXPERIMENTAL RESULTS: SOLAR CELLS

5.1 IV measurements

IV and also spectral response and reflectivity measurements of the bifacial cells are performed on a polished brazen chuck with ~90 % reflectivity for wavelengths > 1000 nm. Thus light transmitting the cell is reflected by the chuck and re-enters the cell from the back side.

On 2-5 Ohmcm R_{Bulk} feedstock V_{OC} values of 638-639 mV under front side illumination (FS) and 636-637 mV under back side illumination (BS) are achieved with a B-BSF R_S of 34, 60 and 82 Ohm/sq. The mean V_{OC} values of the 60 and 82 Ohm/sq cells are 635-636 mV (FS) and 632-634 mV (BS). For the 34 Ohm/sq cells the mean V_{OC} values are 630-632 mV (FS) and 627-630 mV (BS). On 1 Ohmcm R_{Bulk} feedstock V_{OC} values of 634 mV (FS) and 626 mV (BS) are achieved with a B-BSF R_S of 60 Ohm/sq. Due to a not optimal front surface texture on the previously NaOH etched FS (see [5]) the best short-circuit current density ($J_{SC,FS}$) is 35.2 mA/cm^2. The back surface is not textured and the thickness of the back antireflection coating (ARC) is less optimized. Hence the best $J_{SC,BS}$ is 32.9 mA/cm^2. The best values are both achieved with a B-BSF R_S of 60 Ohm/sq. The fill factors (FF) of all the cells are reduced on account of a not optimized metallization featuring interrupted fingers and not optimal contacting. This is ascertained by electroluminescence measurements. The highest FF measured is 75.8 % also on a cell with 60 Ohm/sq B-BSF sheet resistance. The best efficiency (η) achieved under front side (FS) illumination is 16.4 % and 14.4 % under back side (BS) illumination, both with 60 Ohm/sq B-BSF

R_S. The cell with the best η_{BS} shows also the best ratio η_{BS}/η_{FS} of 93 %.

5.2 Spectral response measurements

IQE (see figure 5) and L_{eff} are calculated from the measured external quantum efficiency (EQE) and reflectivity with a computer program written by B. Fischer [1] containing models of P. A. Basore [6] and R. Brendel [7]. For the calculation of L_{eff} the wavelength range from 600 to 720 is approximated with a dead layer model [1] and the wavelength range from 760 to 920 nm is approximated with a model of P. A. Basore [6]. L_{eff} is dependent on the doping level of the base since recombination in the base and BSF band bending are affected by the level of base doping. Due to reflection from the chuck for long wavelengths the IQE is increased compared to an IQE of the same cell measured on an absorbing chuck.

The values of L_{eff} show that the quality of the BS passivation depends on the R_S of the B-BSF and on the thickness of the SiO_2 layer. For all solar cells processed in this work with a R_{Bulk} of 1-5 Ohmcm a B-BSF with a R_S of 60 Ohm/sq leads to the highest mean L_{eff} values of 500-1000 µm for a R_{Bulk} of 1 Ohmcm and 3000-3400 µm for a R_{Bulk} of 2-5 Ohmcm. On 2-5 Ohmcm R_{Bulk} feedstock the cells with a B-BSF of 82 Ohm/sq R_S achieve mean L_{eff} values of 2100-2500 µm and the cells with a B-BSF of 34 Ohm/sq R_S achieve mean L_{eff} values of 2000-2100 µm. The cells fabricated from 1 Ohmcm R_{Bulk} feedstock obtain mean L_{eff} values of 200-700 µm with a B-BSF of 34 Ohm/sq R_S and 200-600 µm without B-BSF. The cells with a base resistivity of 1 Ohmcm are passivated best with an additional SiO_2 layer of 24-30 nm independent of the B-BSF sheet resistance. For those with a base resistivity of 2-5 Ohmcm an additional SiO_2 layer of 19-21 nm leads to the highest mean L_{eff} independent of the B-BSF sheet resistance (see figure 6). The best passivation of all the cells fabricated is achieved using a B-BSF of 60 Ohm/sq and a SiO_2 layer of 20 nm thickness. All cells have an additional SiN_X layer of 75 nm thickness.

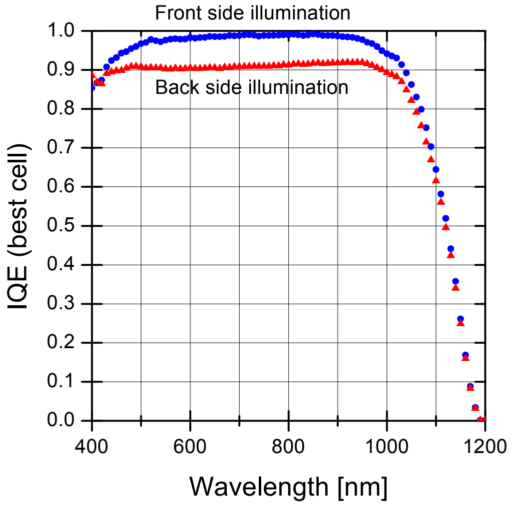

Figure 5: Internal quantum efficiency of the best passivated cell plotted against the wavelength. The FS IQE for long wavelengths is high (64 % @ 1100 nm) and the BS IQE shows nearly no decrease going from 900 to 500 nm, indicating a good surface passivation.

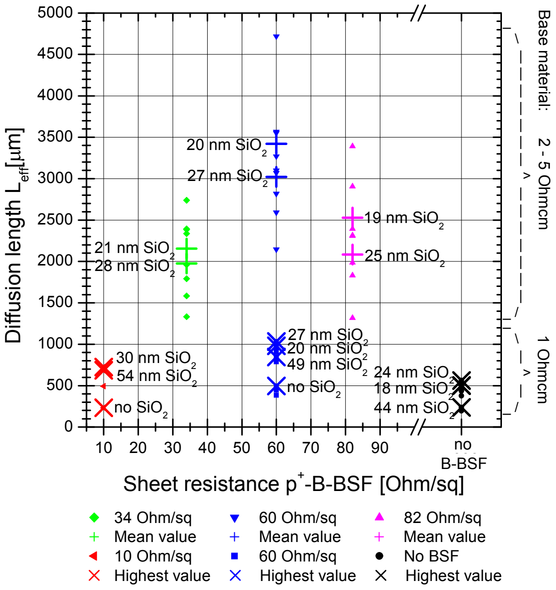

Figure 6: L_{eff} plotted against the sheet resistance of the B-BSF of the cells. The mean values are shown for different thicknesses of the SiO_2 layer.

6 CONCULSION

Our measurements verify the influence of the doping depth and concentration on the passivation quality of a B-BSF. Furthermore, we can demonstrate the influence of the SiO_2 layer on the passivation quality. Optimum values for the bifacial cell concept are found to be 60 Ohm/sq R_S for the B-BSF doping and 19-21 nm for the SiO_2 layer thickness.

7 ACKNOWLEDGEMENTS

The authors would like to thank S. Ohl, B. Rettenmaier and L. Rothengaß for their support during cell processing.

The financial support from the BMU project 0325079 is gratefully acknowledged in particular for the sample characterization equipment.

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