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ScienceDirect

Energy Procedia 92 (2016) 474 – 478

Energy Procedia

6th International Conference on Silicon Photovoltaics, SiliconPV 2016

Optimization of boron diffusion for screen printed n-PERT solar cells

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Abstract

In this study we designed and fabricated *n*-PERT solar cells and we investigated the effect of different boron emitter profile (emitter surface concentration and emitter junction depth) on the cell performance. The emitter depth was varying in the range 0.4 µm and 0.75 µm and the resulting R_{Sh} between 74 Ω/sq and 140 Ω/sq. From QSSPC measurements we observed that a better passivation is achieved in case of low R_{Sh}. almost independently on the emitter depth. However, to achieve the best efficiency at cell level it is necessary to use deeper doping profiles, since for shallow doping profiles the metal recombination losses increase considerably.

Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.

Keywords: Silicon solar cell; *n*-type; p^+emitter; screen printing.

1. Introduction

Solar cells based on *n*-type silicon (Si) have received growing attention from many cell manufacturers due to their higher efficiency potential compared to production cells from *p*-type silicon. Production of solar cells from *n*-type silicon has two big advantages. Firstly, the *n*-type material has higher tolerance to common transition metal impurities, which result in higher minority carrier diffusion length. Secondly, the minority carrier lifetime does not

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1876-6102
Peer review by the scientific conference committee of SiliconPV 2016 under responsibility of PSE AG.
doi:10.1016/j.egypro.2016.07.129

suffer from light induced degradation (LID) due to the boron-oxygen related defects which is frequently found in *p*-type material [1, 2].

The recent progress made in boron emitter formation and surface passivation thereof offers the possibility to produce *n*-type cells with high efficiency at cost competitive way in industrial production. However, the low-cost metallization technique used in industry – screen printing and firing through – limits the open-circuit voltage (V_{OC}) due high recombination losses at p^+ diffused emitters [3-5].

In this experiment we designed and fabricated *n*-PERT (Passivated Emitter, Rear Totally Diffused) solar cells with homogenously diffused front boron emitter and a phosphorous back surface field (BSF) with thermal SiO_2/PECVD SiN_X layers on both sides for surface passivation, and a screen printed and firing-through metallization of commercial Ag paste on both sides.

2. Sample preparation

For the experiment we used 6-inch *n*-type monocrystalline Si wafers (239 cm^2) with base resistivity 2.5 – 3 Ωcm, which were processed using standard industrial process. All wafers were textured using wet chemical alkaline process, followed by a cleaning in HCl, HF, and Piranha solutions. In the next steps diffusion in quartz tube furnace containing $POCl_3$ (n^+ BSF; sheet resistance 75 Ω/sq) or BBr_3 (p^+ emitter), and deposition of thermal SiO_2/PECVD-SiNx stack was done. In the last step the silver finger grid at the front side and rear side was screen printed. The cell process was finished by co-firing of the metal contacts in an infrared heated belt furnace. A schematic cross-sectional drawing of the studied solar cell concept is shown in the Fig. 1.

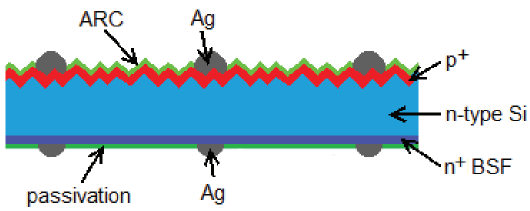

Fig. 1. schematic cross-section of the investigated *n*-PERT cells.

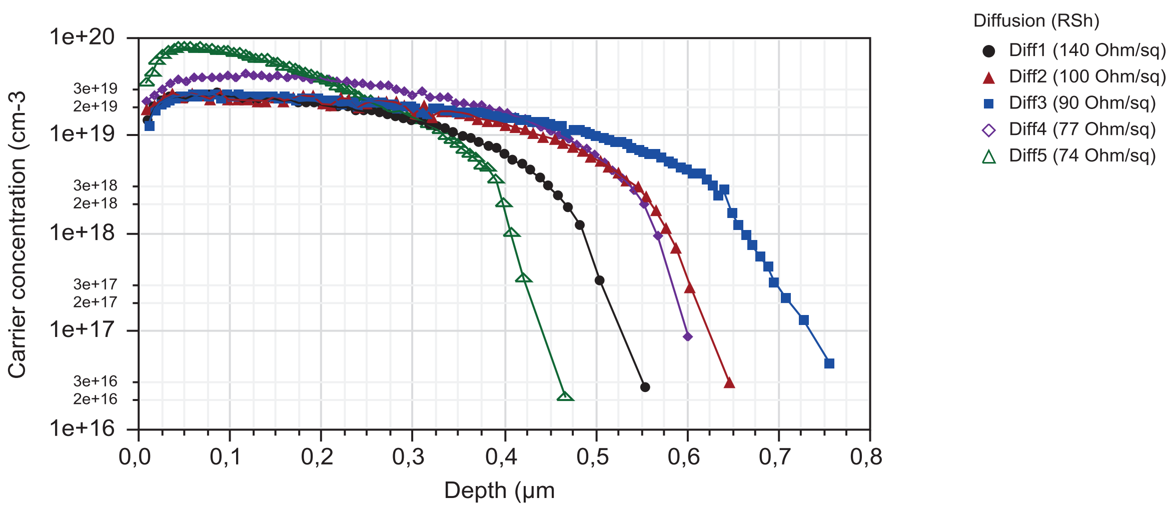

Fig. 2. ECV profiles of the investigated boron diffusion.

The process was the same for all wafers, with the exception of boron diffusion. For this study, five different boron emitters were realized with different doping profile, and resulting sheet resistance. The resulting carrier concentration profiles of these emitters, which were measured by the electrochemical capacitance-voltage (ECV) method [6], are presented in the Fig. 2. The resulting sheet resistance was measured by the four point measurement on both sides of the wafer in 5 × 5 points per wafer side.

The profiles named Diff1 – Diff3 have the same surface concentration and they differ from each other in the emitter depth. The profile Diff4 has same depth as Diff2, but with higher surface concentration. The profile Diff5 is the shallowest profile with the highest surface concentration of boron.

3. Results

3.1. Implied V_{OC} and J_0

Before printing the metallization grid, but after a firing step, we measured the implied V_{OC} (iV_{OC}) and dark saturation current density (J_0) of the precursor cells using a quasi-steady-state photoconductance technique (QSSPC) [7]. Values of iV_{OC} and J_0 were obtained at 1 sun illumination and at injection level of $\Delta n = 3 \times 10^{15}$ cm^{-3}. The measured values of each sample are compared in the Fig. 3. It is obvious that profiles Diff1 (74.4 fA/cm^2; 681 mV), Diff2 (81.5 fA/cm^2; 680 mV), and Diff3 (73.9 fA/cm^2; 682 mV) gives better passivation, higher iV_{OC}, and lower J_0 compared to the profiles Diff4 (92.4 fA/cm^2; 675 mV) and Diff5 (103 fA/cm^2; 674 mV). The most important parameter for passivation is the emitter surface concentration, not the emitter depth.

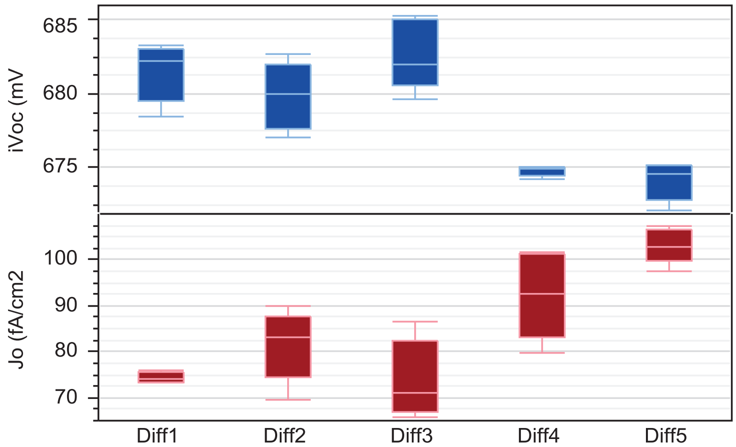

Fig. 3. iV_{OC} at 1 sun and J_0 of the cell precursors (before metallization). The J_0 was extracted at an injection level of $\Delta n = 3 \times 10^{15}$ cm^{-3}.

3.2. IV measurement

The metalized solar cells were investigated by IV measurements to determine the values of short-circuit current (J_{SC}), V_{OC}, fill factor (FF), and efficiency. The solar cells were measured under AM1.5 spectrum with illumination intensity of 1000 W/m^2 and temperature of 25 °C. The samples with doping profile Diff2 and Diff3 achieve the lowest J_{SC} and the best V_{OC}, efficiency, and fill factor (Diff2: 39.4 mA/cm^2 and 650 mV; Diff3: 39.3 mA/cm^2 and 650 mV). The high value of J_{SC} (39.5 mA/cm^2) in case of samples with doping profile Diff1 and to this value relating low V_{OC} (643 mV) is caused by insufficient emitter depth, which leads to higher recombination under the metal contacts. These results showed that, for screen printed and firing contacts, there is a trade-off between efficiency potential demonstrated by the cell precursors and metalized cells. The best compromise is achieved for emitter profiles with low surface concentration (that gives better surface passivation) and higher emitter depths (that reduces the contact recombination losses).

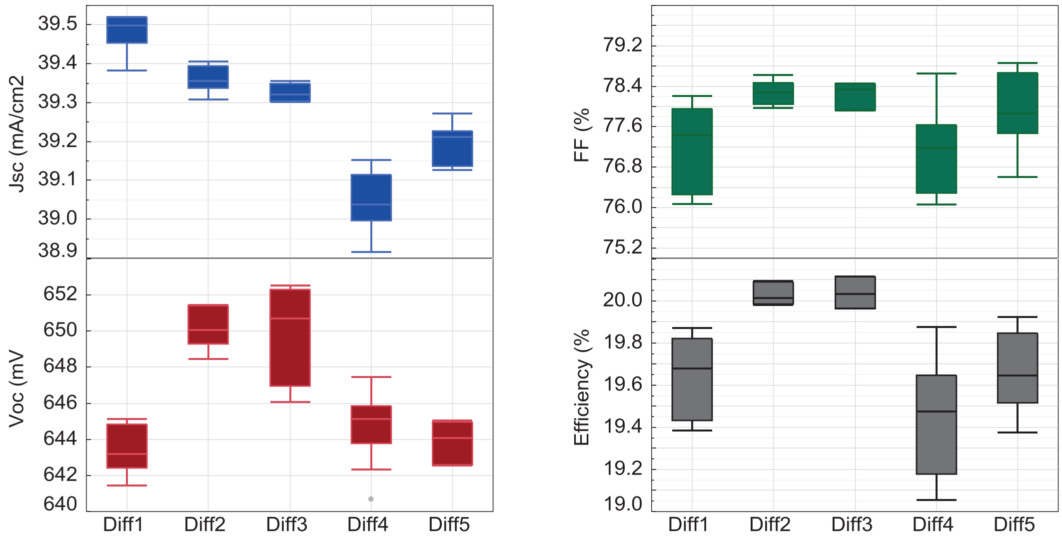

Fig. 4. solar cell parameters obtained by IV measurement at 25 °C and under AM1.5spectrum with illumination intensity of 1000 W/m^2.

4. Conclusions

Within this work we have presented the influence of boron emitter properties (surface carrier concentration, depth, and sheet resistance) on the solar cell parameters. From QSSPC measurements we observed that better passivation quality (high iV_{OC} and low J_0) was achieved in case of profiles with lower surface carrier concentration (profiles Diff1 – Diff3). It follows that most important parameter for passivation is the surface carrier concentration, rather than the junction depth. From the IV measurement we found out that the profile Diff1 do not have sufficient depth, which leads to higher recombination under the metal contacts compared to profiles Diff2 and Diff3. The best solar cell efficiency was achieved for emitter profiles with low surface concentration (good surface passivation) and high junction depth (reduction of contact recombination losses).

Acknowledgements

The article was supported by project no. FEKT-S-14-2300 A new types of electronic circuits and sensors for specific applications.

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