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Industrial Solar Cells Featuring Carrier Selective Front Contacts

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Abstract: We present an industrially applicable approach to integrate boron doped carrier-selective passivating contacts to the front side of silicon solar cells. A single BBR_3 diffusion simultaneously forms the highly doped p^{++} region within the Poly-Si as well as the lowly doped buried junction below the AlO_X/SiN_X stack. A self-limiting wet etching process allows the removal of the Poly-Si at the non-contacted region between the fingers, whilst stopping at the wafer/SiO_X interface. The final structure combines the high-level passivation and transparency of the AlO_X/SiN_X together with the good passivation and transport properties of the carrier selective contact.
In Quokka 3 [1] simulations, the main solar cell parameters are analysed as a function of the saturation current density for the contacted region versus the non-contacted. The simulations show that implementing the Poly-Si below the metallization on the front side can boost the efficiency from 23.1% to 23.5%, so an effective gain of 0.4%.

In recent years, carrier-selective passivating contacts based on a thin SiO_X layer covered by a highly doped Poly-Si have demonstrated their potential in world record devices [2], [3]. To date they have been applied mainly to the solar cell rear side. Thanks to their excellent contact properties, the front side often then becomes the limiting efficiency factor, namely the recombination losses at the contact openings [4]. These losses are targeted by using a Poly-Si contact on the front. However, using a full area Poly-Si is unfavourable, when compared with the low parasitic absorption of an Al_2O_3/SiN_X stack. Therefore a patterned front Poly-Si below the metallization becomes the focus of our research. We propose a process sequence forming the shallow-doped region (200-400 Ω/sq) below the Al_2O_3/SiN_X stack in a single diffusion step together with the doping of the Poly-Si with a surface concentration above 10^{20} cm^{-3}, providing low resistance with the metallization.
In this contribution intrinsic Poly-Si layers are prepared by Jinko solar upon a thin thermal SiO_X (<2nm), grown on 180 µm thick double side textured n-type wafers, having a bulk resistivity of 2 Ωcm. Symmetrical test samples are fabricated in a tube furnace either in a $POCl_3$ or a BBr_3 atmosphere and lead to implied open circuit voltages (iV_{OC}) above 730 mV and 700mV, respectively.
A self-limiting wet chemical etching process allows the removal of the Poly-Si while keeping the shallow diffusion at the wafer surface, shown in Figure 1b, together with the sheet resistance R_{SH}. After etching-off the Poly-Si, buried junctions are re-passivated by Al_2O_3/SiN_X. The achieved iV_{OC} values of ~690mV

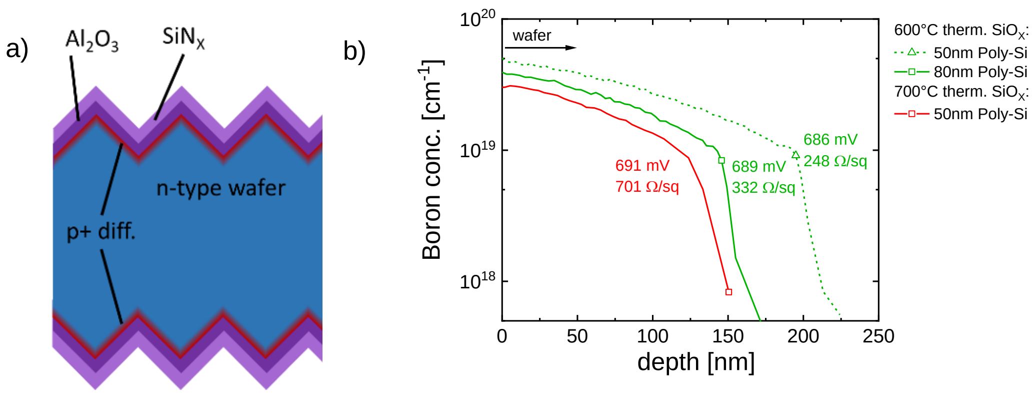

Figure 1 - a) Sketch of the measured symmetrical test structure after the poly-Si is etched off and the surface is re-passivated by Al_2O_3/SiN_X. b) Boron doping profiles measured by ECV for different SiO_X temperatures and Poly-Si thicknesses. The sheet resistance as well as the iV_{OC} values after re-passivation with an Al_2O_3/SiN_X stack are indicated next to each condition.

(J_0 ~ 30mA/cm^2) are in agreement with literature values for Al_2O_3/SiN_X passivation of such doping profiles [5]. This proves that the wafer surface can be re-passivated between the fingers with high quality after etching off the poly-Si layer.

The potential and limitations of this approach is investigated using Quokka 3 [1] simulations. A metallization covering 5% of the illuminated area is used representing an industrial solar cell (**Figure 2**a-d). The key photovoltaic parameters (fill factor (*FF*), open-circuit voltage (V_{OC}) and efficiency) are plotted as a function of the saturation current density J_0 for the contacted versus non-contacted region. An optimum for the *FF* is observed for an R_{SH} between 200-500Ω/sq, which enables 10fA/cm^2 < $J_{0,\text{non contacted}}$ < 30fA/cm^2. The V_{OC} is mainly driven by $J_{0,\text{ non-contacted}}$ due to the larger surface area. The contribution of $J_{0,\text{contact}}$ becomes more apparent in case of low $J_{0,\text{ non-contacted}}$. The white star on the graphs indicates a state-of-the-art contact without Poly-Si below the metallization ($J_{0,\text{contact}}$ = 500fA/cm^2; $J_{0,\text{ non-contacted}}$ = 20fA/cm^2). The black star indicates a contact using the proposed approach with Poly-Si below the metallization using values which have been achieved experimentally in our lab ($J_{0,\text{contact}}$ = 15fA/cm^2; $J_{0,\text{ non-contacted}}$ = 30fA/cm^2). The simulations show that, using this approach, the V_{OC} improves by 10mV (from 698mV to 708mV) leading to an improvement in efficiency from 23.1% to 23.5%. The effective gain of 0.4% evidences the strong potential of this approach to boost the efficiency of the solar cell while keeping the fabrication process simple.

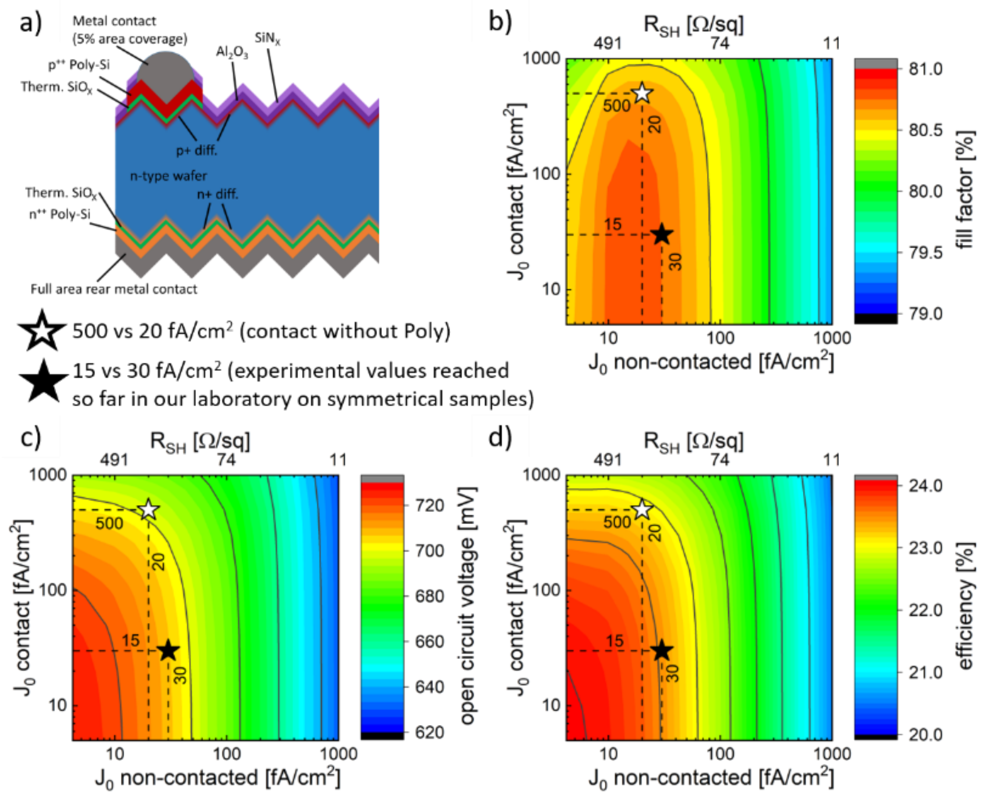

Figure 2 - a) Solar cell structure used for the simulations. b) fill factor, c) open-circuit voltage and d) efficiency as a function of J_0 below the metallization ($J_{0,\text{ contact}}$) versus J_0 between the fingers ($J_{0,\text{ non-contacted}}$).

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