Firing-through metallisation of PERT-like cells using µc-Si(n) as thin rear side full area passivating contact

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ABSTRACT

Tunnel oxide passivating contacts are compatible with manufacturing processes at elevated temperature (>700°C) and have enabled solar cell power conversion efficiencies above >25.7% [1]-[2]. In order to bring together high efficiencies and the process technologies currently in use in industry, a key step will be the contact formation with silicon nitride (SiNx) and a firing-through metallisation. We present a firing-through metallisation approach for n-type passivating rear contacts that consist of a tunnelling oxide and an n-doped bilayer of a-SiO_x and µc-Si. We find implied Voc up to 738 mV and contact resistivities as low as 20 mΩcm^2. Implemented into 6-inch solar cells with a B-diffused emitter on the front, the best cell showed a V_{oc} of 687 mV, FF 79.4 % and an overall efficiency of 22.2 %, proving the compatibility with metallisation by a conventional firing-through process. In view of the higher iVoc of the passivating µc-Si(n) contact, higher cell efficiencies are expected through improvements of the front side.

1. EXPERIMENTAL

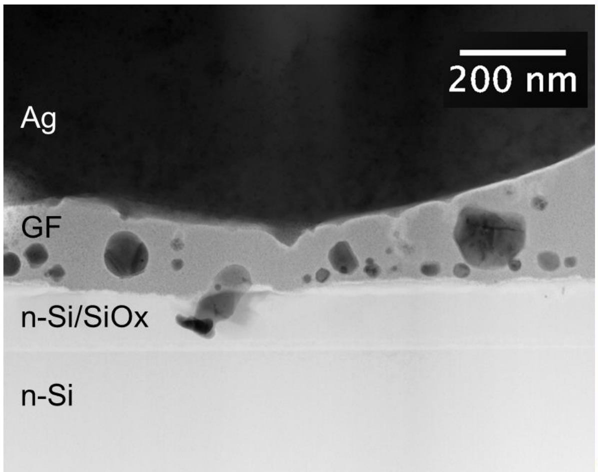
Symmetrical test structures were fabricated using boron doped <100> shiny etched 4-inch float zone (FZ) wafers with a resistivity of ~2 Ωcm and a thickness of 200 µm. After a standard wet cleaning process, a thin SiO_x layer (~1.4 nm) was grown by a wet chemical oxidation in hot nitric acid (69% w.t at 80°C). Afterwards, an n-doped layer stack was deposited by plasma enhanced chemical vapour deposition (PECVD) at a temperature of 200°C and at a plasma frequency of 40.6 MHz. The total thickness of the stack is approximately 120 nm wherein a 20nm thick layer of a-SiO_x provides a high thermal stability [3] and a 100 nm thick layer µc-Si provides contact to the metallisation. In a first step, we fabricated symmetrical test structures to investigate the impact of the metallisation process on recombination losses and charge carrier extraction. To activate and further crystallize the contact, the samples were annealed at 900°C for 15 min in a tube furnace. Subsequently, a SiN_x layer was deposited on both sides and contact structures were screen-printed with commercially available Ag pastes. Finally, the samples were fired in an in-line firing furnace. Samples for electron microscopy were prepared preparing a thin lamella with focused ion beam. TEM images and energy-dispersive X-ray spectra were acquired in a FEI Tecnai Osiris equipped with four silicon drift detectors and operated at 200 kV.

Solar cells were fabricated from 6-inch (M2) single side textured (SST) Cz wafers featuring a B-diffused emitter at their front (supplied by Meyer-Burger, Germany). After cleaning, the precursors received the same interfacial oxide as above, followed deposition of the bilayer stack on the rear side prior and annealing at 900°C for 15 min. After a wet cleaning sequence, AlO_x was deposited on the front of the cell and a SiN_x layer was deposited on both sides. Finally, an Al-Ag paste was printed on the front whereas a two different commercially available Ag pastes were tested for the rear side passivating contact. The samples were fired at 800°C. The IV characteristics were measured using a Wacom sun simulator with an AM1.5 G irradiance spectrum at 1000 W m^{-2} (class AAA).

2. RESULTS

2.1. Layer structure & direct metallisation pre-test

The STEM High-Angle Annular Dark-Field (STEM HAADF) image in Figure 1 shows that the Ag particles do not penetrate farther than 30-50 nm into the n-type µc-Si, hence making a direct contact with the passivating contact stack, yet without attacking the chemical oxide. The PL image confirms that passivation is maintained underneath the printed/fired Ag-pads and on symmetrical test structures iV_{oc} values of 738 mV are reached with contact resistivites as low as 20 mΩcm^2.



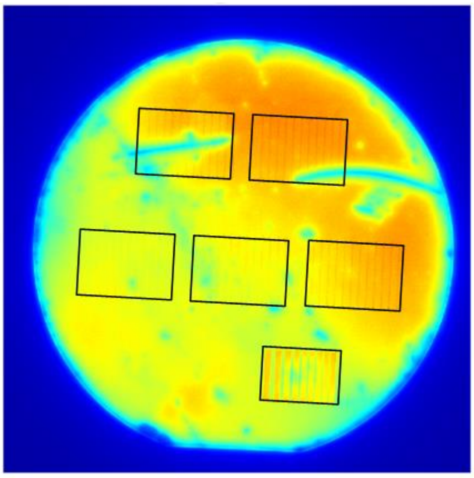
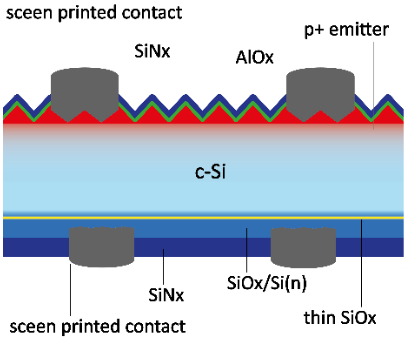


Figure 1: Scanning TEM high-angle annular dark-field image of the contact with screen-printed Ag paste after firing at 800°C (left) and photoluminescence image of a 4-inch symmetrical sample after firing (right)

2.2. 244 cm^2 cells fabrication and analysis

Proof-of-concept solar cells based on 6-inch wafers were fabricated using our µc-Si(n) layer stack. A comparison between two different commercially available Ag pastes, named here paste A and B respectively, is presented. As seen in Figure 2, a trade-off between V_{oc} and FF is visible between the two pastes. In a measurement with edge-masking, efficiencies up to 22.2% and FF up to 81.7% were reached, highlighting the excellent contact between the Ag paste and our electron selective passivating contact.

As shown in the previous section, our rear side passivating contact has a V_{oc} potential up to 738 mV and does not show an increased recombination rate in the metallized area. We can thus conclude that for both pastes the Voc of the finished cells is dictated by recombination losses at the front. Accordingly, improvement of the B-diffused emitter is required in order to fully exploit the potential of the rear side.



244cm² cell with Ag paste A) or B)	V_{oc} (mV)	J_{sc} (mA/cm²)	*FF* (%)	η (%)
A)	687.1	40.6	79.4	**22.2**
B)	675.0	40.3	81.0	**22.0**
B) edge-masked (220cm²)	673.0	40.4	81.7	**22.2**

Figure 2. Final cell structure with full area µc-Si(n) layer on rear side and diffused B front emitter (left) and 244cm² cell results with two commercially available Ag pastes A and B respectively (right)

3. CONCLUSION

We investigated a passivating contact structure featuring a µc-Si(n) layer stack that was directly metallised with a standard firing-through Ag paste. After screen-printing and firing, PL imaging suggests that the passivation is not harmed by the metallisation. Cross-sectional electron microscopy showed the confinement of the Ag crystallites within the first 30-40 nm. Finally, proof-of-concept n-type PERT-like solar cells were produced on full area M2 substrates. Two different commercial Ag paste were tested and fired. The two Ag-pastes showed a trade-off between FF and V_{oc}. For paste A, a Voc of 687 mV and a FF of 79.4% were obtained. From the implied Voc of test samples we conclude that the Voc is limited by the front side. For paste B, a lower V_{oc} of 675 mV and a higher a higher FF of 81.7% is obtained (with edge-masking). The conversion efficiency of this cells reaches 22.2%.

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