THE STARFIRE PROJECT: TOWARDS IN-LINE MASS PRODUCTION OF THIN HIGH EFFICIENCY BACK-CONTACTED MULTICRYSTALLINE SILICON SOLAR CELLS

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ABSTRACT: In the StarFire project, the partners ECN, Ferro and Solland develop several breakthrough technologies with the goal of realizing of 17% average cell efficiency on 150 μm thin wafers in combination with in-line cell processing and back-contacted cell and module technology. In this contribution the first prototype cells are presented, the status of the project is discussed and the road towards mass production is drawn.

Keywords: Back contact, Multicrystalline silicon, Passivation

1 INTRODUCTION

1.1 The Sunweb cell

The photovoltaic industry's race towards grid parity progresses mainly through technological developments enabling higher efficiencies, lower material usage and cost-effective production methods. For multi-crystalline silicon wafer-based technology, the work horse of the photovoltaic industry, one key and up-coming breakthrough is the adaptation of manufacturing processes for back contact cell concepts using the so-called metal wrap-through (MWT) technology [1-3].

The main attribute of back-contact cell technologies is not only that they provide higher solar energy conversion efficiencies, but, moreover, that they enable new and revolutionary module concepts resulting in higher processing throughput, less cell breakage and higher module efficiency. Solland Solar and partners are among the first pioneers in the industrialization of the MWT technology. Sunweb, Solland's back-contact solar cell, is now fully ready for industrial production. The successful transfer from lab to industrial production is an important milestone and celebrated by giving the cell its name: "Sunweb".[*]

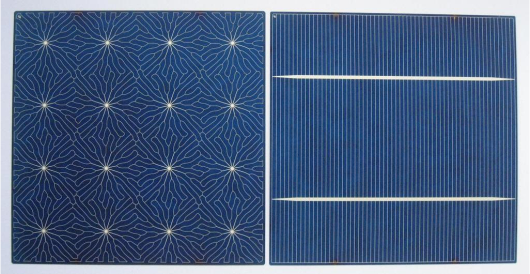

Figure 1: Photograph of the Sunweb cell (left) and a conventional solar cell (right).

Figure 1 shows the front side of the Sunweb cell next to a conventional cell. In the Sunweb cell there are no busbars. Instead, the current is guided to the rear side of the cell through 16 holes. The rear side of the Sunweb cell (not shown in the figure) consists of a full aluminum print, with silver dots on the positions where the cells are to be soldered into a module.

1.2 The Starfire project

In the Starfire project the partners Solland, ECN and Ferro are developing the technology for "Sunweb 2.0". The main idea of the project is to develop the cell technology that enables high efficiency (target: 17%) on very thin wafers (target: 150 μm). The largest part of the project deals with the implementation of a dielectric rear passivating film that replaces the aluminum BSF. The passivating film removes the three main road blocks that prevent successful implementation thin wafers in existing multi-crystalline silicon production lines:

1. Mechanical – Conventional thin cells suffer from increased cell bow and resulting cell breakage. A dielectric passivating film on the rear completely eliminates the cell bow.
2. Optical – Conventional thin cells suffer from reduced light absorption and resulting lower short-circuit current. A dielectric passivating film on the rear allows the design of a better back reflector that sends the non-absorbed light a second time through the wafer.
3. Electrical – Conventional thin cells suffer from the high recombination velocity of the aluminum BSF on the rear side (industrial BSF: 1000-1500 cm/s). A dielectric passivating film can bring the effective rear recombination velocity to values of 500 cm/s and below.

In this paper the first rear passivated Sunweb prototype cells are presented, the status of the Starfire project is discussed and the road towards mass production is drawn.

2 CELL PROCESSING

All experiments were conducted on 156×156 mm^2 multi-crystalline silicon wafers with thicknesses between 150 and 200 μm (before processing). In order to minimize the mechanical load on the fragile 150 μm wafers, we stick to in-line processing wherever we can. In addition, to minimize handling and end up with a cost-effective process we pursue technological routes that hold the promise of only the very minimum of additional process steps.

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[*] At ECN, the acronym "PUM" is used for Sunweb-like cells with Al-BSF, whereas "ASPIRe" stands for Sunweb-like cells with a dielectric rear passivation.

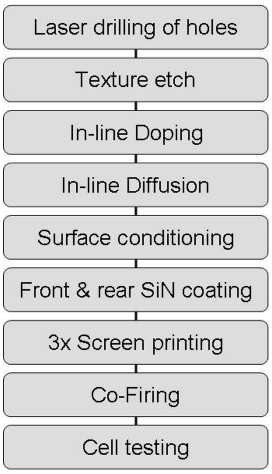

Figure 2: Processing sequence of a rear passivated Sunweb cell.

The full processing of a rear passivated Sunweb cell then comprises of laser drilling of the holes, iso-texturing, doping with phosphoric acid, diffusion in an in-line belt furnace, front & rear surface conditioning (including glass removal), front & rear SiN coating, three screen-printing steps, one co-firing furnace and finally the testing and classification of the cells. Reference conventional cells can be made according to the same process sequence, merely by leaving out two process steps; the hole drilling and the rear side SiN coating process. For reference Sunweb cells, only the rear SiN coating process has to be omitted.

3 RESULTS

3.1 In-line emitter

Part of the pursued efficiency gain should come from the development of a new in-line emitter. We pursue a route in which we decrease the phosphorous surface concentration, thereby raising the open-circuit voltage of the solar cell by ~5 mV and the short-circuit current by ~0.1 A (0.4 mA/cm^2) [4]. Besides the emitter process, we develop new front pastes in order to contact this novel emitter [5]. So far, an efficiency gain of around 0.1% absolute with respect to a conventional industrial in-line emitter has been realized.

3.2 Metal wrap-through

The metal wrap-through connection from front to back contact has always played a crucial role both in the processing and in the device performance of MWT cells, particularly regarding the ohmic shunt (R_{sh}) [6] and 10V reverse current (I_{rev}) of the cell. Within the Starfire project, a new 'plug paste' was designed to fill up the holes in a single conventional screen print process. For this new paste we managed to find a process window in which MWT-related shunts are almost fully eliminated. Typical values for ohmic shunt and 10 V dark reverse current of Sunweb cells now lie around $R_{\mathrm{sh}} \approx 100$ Ohm (25 kOhm cm^2) and $I_{\mathrm{rev}} \approx 0.2$ A (1 mA/cm^2), respectively, as is shown in Figure 3. More information on the metal-wrap through connection is presented in [7].

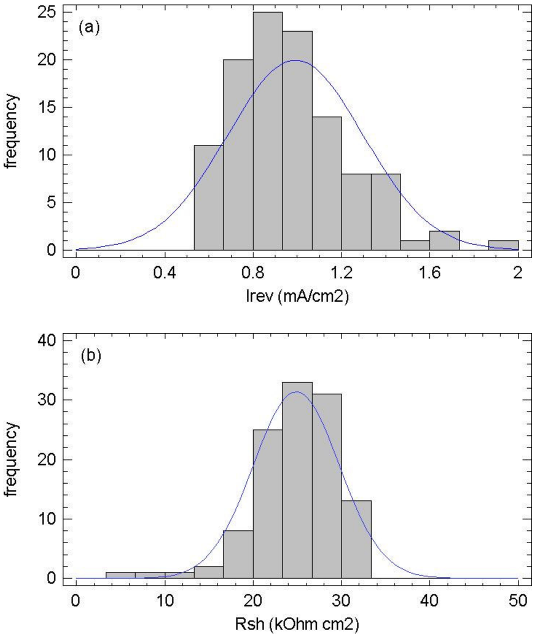

Figure 3: Histogram showing the distribution of R_{shunt} (top) and I_{rev} (bottom) for a typical Sunweb experiment. The solid line shows a normal distribution fit and is meant as a guide to the eye.

3.3 Rear passivating film

In industry and research institutes alike numerous rear side passivating films are being investigated. So far, no clear consensus has been obtained as to which coating is the most suitable for industrial processing of mc-Si solar cells. Within the Starfire project we pursue the implementation of a single SiN passivating film. Surface recombination velocities below 20 cm/s are easily obtained with this coating [8], which basically means that recombination at the p-type Si / SiN interface is not limiting the device performance. The biggest advantage of using a single SiN layer is that it is compatible with a simple co-fired local BSF as is further discussed in section 3.4.

3.4 Rear aluminum metallization

The rear aluminum metallization is of crucial importance to the performance of rear passivated Sunweb cells. If the resistivity of the rear aluminum lines would be too high, the rear aluminum would severely limit the fill factor of the corresponding solar cells. In addition, both the local BSF quality and the aluminum surface coverage have a strong impact on the effective rear surface recombination velocity. To tackle this problem we developed an aluminum paste and corresponding process that yields ~60 µm high aluminum lines under which a ~5 µm thick BSF is formed [9], as shown in Figure 4.

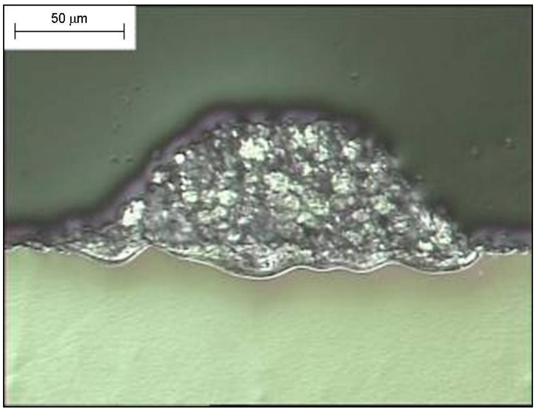

Figure 4: Cross section of a ~60 μm high aluminum finger with a ~5 μm thick BSF fired through the rear passivating silicon nitride film.

When comparing the surface recombination velocities of ~10^1 cm/s for SiN versus ~10^3 cm/s for a BSF it immediately becomes clear that the effective rear surface recombination velocity will be determined by the surface coverage of the aluminum paste. Figure 5 shows this contrast in surface recombination velocities in a μ-PCD charge carrier lifetime image of a local BSF test structure fired through a SiN passivated mc-Si wafer.

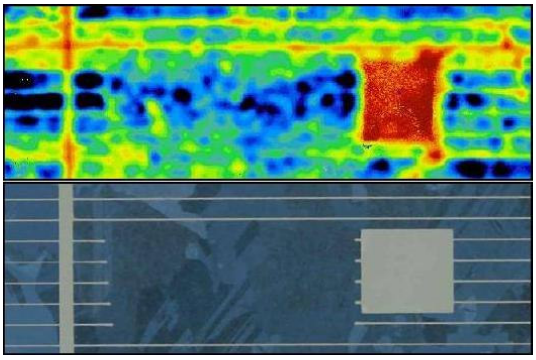

Figure 5: μ-PCD image (top) and photograph (bottom) of a test structure used to investigate the effective rear surface recombination velocity. The charge carrier lifetime is lowest in the dark red regions and highest in the dark blue regions.

3.5 First integrated prototypes

Combining the technologies described in sections 3.1 to 3.4, we managed to fabricate the very first prototypes of the rear passivated Sunweb cells. The specific merits of our Sunweb technology become obvious once more, if one considers that now the surface coverage and finger length on both the front *and* rear surface can be significantly reduced with respect to conventional busbar technology.

Figure 6 shows a photograph of one of these first cells. So far, efficiencies close to 16% have been obtained [3]. In the remainder of the project, the processes for these integrated devices will be optimized in order to reach the project goal of 17% efficiency.

Table I: IV parameters of the first rear passivated Sunweb cells compared to a reference Sunweb group (10 cells per group, 160 μm wafers)

	η (%)	FF (%)	V_{oc} (mV)	I_{sc} (A)
Sunweb	16.0	77.1	616	8.20
Rear passivated Sunweb	15.9	76.2	616	8.20

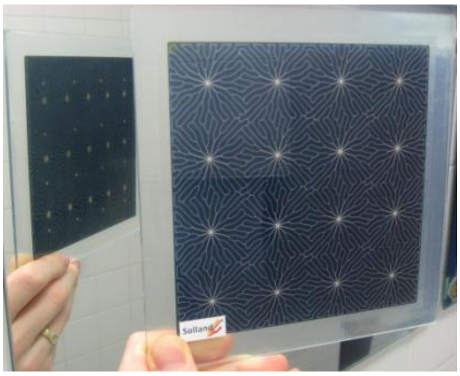

Figure 6: Photograph of one of the first rear passivated Sunweb prototypes.

4 CONCLUSIONS & OUTLOOK

The Starfire project focuses on developing the cell technology needed for making back contacted solar cells on very thin multi-crystalline silicon wafers. The very first prototypes reached efficiencies close to 16%. Optimization of these integrated devices has begun and should lead to a cell efficiency of 17%. Since the chosen processing route lies very close to what is used in production lines right now, the Starfire cell concept can be quickly transferred to mass production.

ACKNOWLEDGEMENT

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