

## PROGRESS IN LASER-BASED FOIL METALLIZATION FOR INDUSTRIAL PERC SOLAR CELLS

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**ABSTRACT:** In this work we present our latest results using aluminium foil as rear side metallization for solar cells with dielectric passivation and laser fired contacts (LFC). Beside the reduction of the material costs compared to screen printed aluminum paste, it is possible to use thinner or even no SiN<sub>x</sub> capping layer on the rear side Al<sub>2</sub>O<sub>3</sub> passivation, without a decrease in short circuit current density  $j_{sc}$  or open circuit voltage  $V_{OC}$ . Therefore, the superior reflection of the air gap between passivation and aluminum foil is independent from the passivation layer thickness, as previously announced. Damp-heat-test reveals that a 10 nm thin SiN<sub>x</sub> capping is sufficient to protect the rear side passivation layer from accelerated aging. With such an optimized passivation and a special front side screen printed metallization scheme without busbars, designed for multi-busbar interconnection, we achieve a cell efficiency of 21.3 % on magnetically cast Cz-Si (156×156 mm<sup>2</sup>).

Keywords: Laser Processing, Manufacturing and Processing, Metallization, Contacting

### 1 INTRODUCTION

To increase the efficiency of solar cells new cell concepts are finding their way into production. One concept is the highly efficient passivated emitter and rear cell (PERC) introduced by Blakers *et al.* [1], which at least needs two additional process steps – the deposition of a passivation layer on the rear side and the forming of local electrical contacts from the screen printed aluminium, through the passivation layer to the silicon bulk by single laser fired contacts (LFC) [2]. But every additional process step causes costs, which should be as low as possible. Another cost driver is the material price and the high consumption of the aluminium rear side screen printing paste. Therefore, LFC in combination with aluminium foil is an easy-to-apply and cost effective technique to metallize and contact the rear side in one single step [3]. Furthermore, a rear side passivation for screen printed metallization needs an additional SiN<sub>x</sub> capping, which is necessary to protect the Al<sub>2</sub>O<sub>3</sub> passivation layer beneath against the paste during the fast firing step and to optimize the rear reflection. In the case of the Al-foil a thinner or no protection layer is needed and the air gap between foil and passivation leads to an increased internal reflection [4]. A decrease of the capping layer thickness is an additional cost saving possibility of note. All previously shown foil cell results, obtaining an efficiency up to  $\eta = 20.5\%$  [5] e.g., had a thick passivation layer optimized for the use with screen printed aluminium paste.

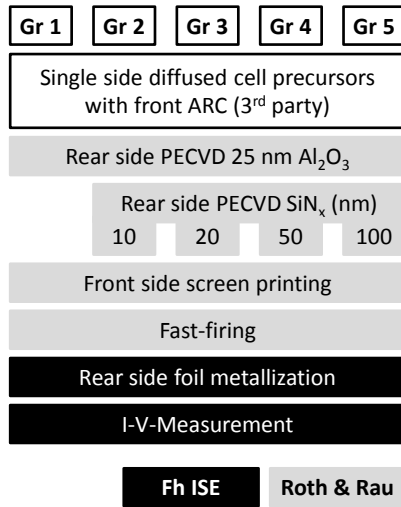
In this paper we adapt the backside passivation to fulfill the foil's requirements and investigate the influence on the laser process. The aim is to optimize lasing time, cost saving, foil adhesion and contact properties while retaining a high efficiency.

### 2 EXPERIMENTAL DETAILS

To determine the influence of the passivation stack, especially the SiN<sub>x</sub> capping layer thickness, in combination with a rear side foil metallization, third party precursor-wafers were used, which had an emitter with a

sheet resistance of 80  $\Omega/\square$  and an anti-reflection coating (ARC) on the front side. The precursors are made of 156×156 mm<sup>2</sup> full-square Czochralski (Cz) silicon wafer with a base resistivity of  $\rho = 2.5 \Omega\text{cm}$ . Deposition of the rear side passivation and front side metallization with state of the art screen printed contacts was done at the pilot line of our partner Roth & Rau. For the deposition of the dielectric layers, composed of a 25 nm thin Al<sub>2</sub>O<sub>3</sub> passivation layer for all groups and a variable SiN<sub>x</sub> capping layer thickness  $d$ , the plasma enhanced chemical vapour deposition (PECVD) technique with the MAiA<sup>®</sup> R 2.1 tool was applied. The capping layer varied from 0 up to 100 nm ( $d = 0, 10, 20, 50$  and 100 nm), where the 100 nm thick SiN<sub>x</sub> layer on top of the Al<sub>2</sub>O<sub>3</sub> is a current industrial standard to protect the passivation from the screen printed paste during the fast firing and to optimize the internal reflection of the backside. Therefore, the group with the thickest stack serves as a reference. Next all the cells were metallized on the front side with screen printed silver paste and fast-fired at the same temperature. Afterwards the rear side metallization, applying aluminium foil and laser fired contacts was processed at Fraunhofer ISE using a prototype tool from Innolas Solutions GmbH, based on the ILS TT automated laser machine. Thereafter the measurement of the I-V characteristics ( $\eta$ ,  $FF$ ,  $j_{sc}$  and  $V_{OC}$ ), the internal reflection  $R$  at the rear side and the long-time stability dependent on the dielectric stacks were carried out. To determine the stability of the passivation under accelerated aging, the non-laminated solar cells were put directly into a climatic chamber, with 85 °C and 85 % humidity for 1000h (damp-heat-test, DH). Since only the degradation of the dielectric layers shall be observed, no tabbing ribbons or laminates were used, which could falsify the result. Each week the illuminated I-V characteristics were detected to log the process of degradation. Additional to the cells with front side metallization, three only passivated wafers per group were processed without metallization - the so called implied open circuit voltage ( $iV_{OC}$ ) samples. These samples allow the determination of the  $iV_{OC}$ , the splitting of the quasi Fermi levels, thus evaluating the passivation quality before and after the fast firing step with the quasi

steady state photo conductance (QSSPC) measurement method [6]. An overview of all five groups is shown in Figure 1.

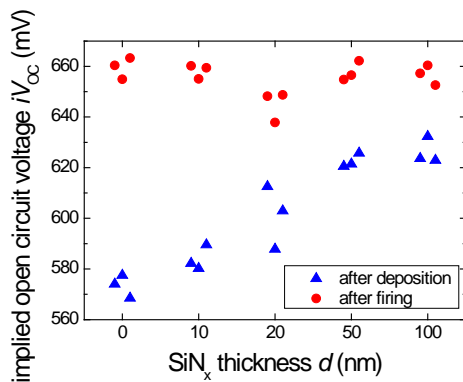


**Figure 1:** Overview of the different groups and respective dielectric stacks.

Subsequently the best passivation process was used to make highly efficient cells of magnetically cast Cz (mCz) silicon wafer, with a base resistivity of  $\rho = 1.0 \Omega\text{cm}$ . These cells were processed almost completely on Roth & Rau’s pilot line. Only the rear side aluminium foil metallization was carried out at Fraunhofer ISE. Special features of the cells were a double ARC layer and the lack of screen printed busbars on the front side, designed for multi-busbar interconnection.

### 3 RESULTS AND DISCUSSION

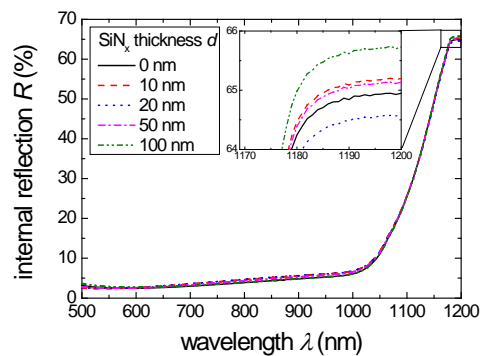
As can be seen in Figure 2, all passivation stacks reach a similar  $iV_{OC}$  value of 660 mV after firing, except the  $d = 20$  nm group 3. A problem during the deposition of that layer is assumed to be responsible for the lower  $iV_{OC}$  value of 640 mV, thus can be the reason for the wider distribution of the  $iV_{OC}$  values from group 3 directly after deposition, too. For this reason, that group will not be considered in the following.



**Figure 2:** Implied VOC results directly after deposition of the capping layer (▲) and after fast firing (●).

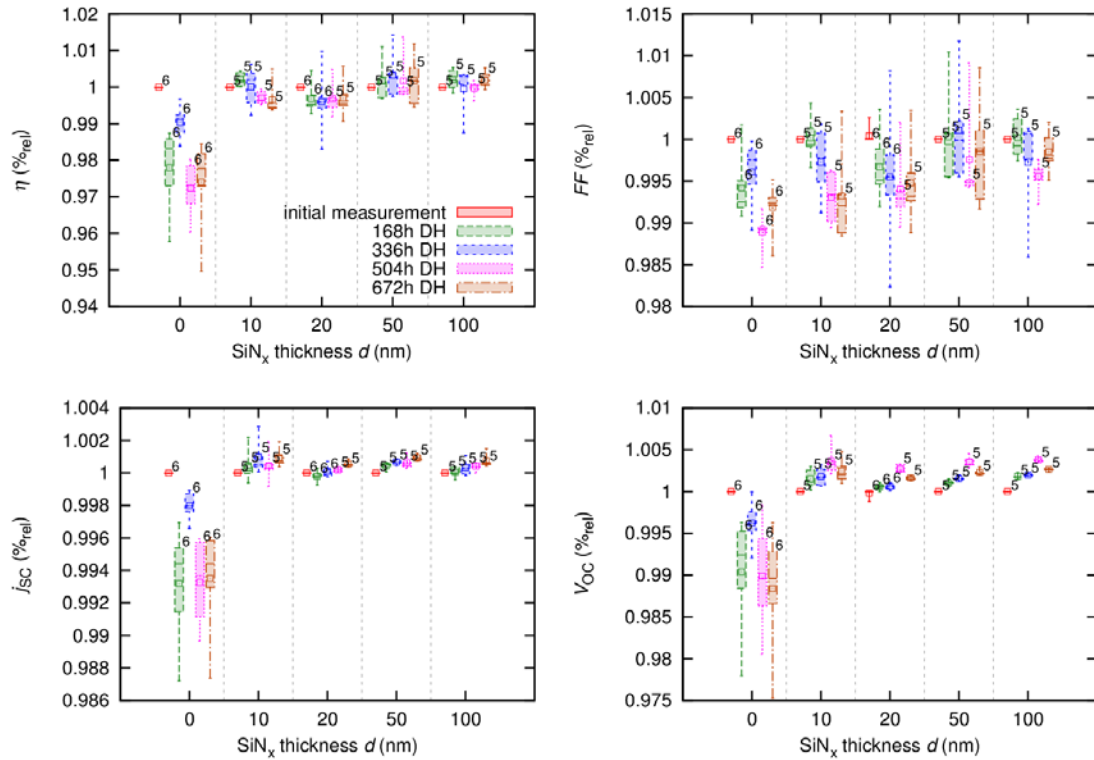
The thermal contribution of the  $\text{SiN}_x$  deposition rises with increasing layer thickness, which leads to an activation of the  $\text{Al}_2\text{O}_3$  layer in parts and therefore to a higher  $iV_{OC}$  value directly after deposition. That difference cannot be observed after the fast-firing process. No decrease in passivation quality can be noticed depending on the thickness of the  $\text{SiN}_x$  capping layer.

The previously shown high internal reflection at the rear side, due to a thin air gap between the aluminium foil and the dielectric layer, is independent from the capping layer thickness, as can be seen in Figure 3. All groups reach a maximum value of  $R = (65.1 \pm 0.4) \%$  at 1200 nm wavelength. Therefore, the air gap dominates the reflection behaviour at the back side of the solar cell and no detrimental influence of a thinner capping layer on  $j_{sc}$  can be observed.

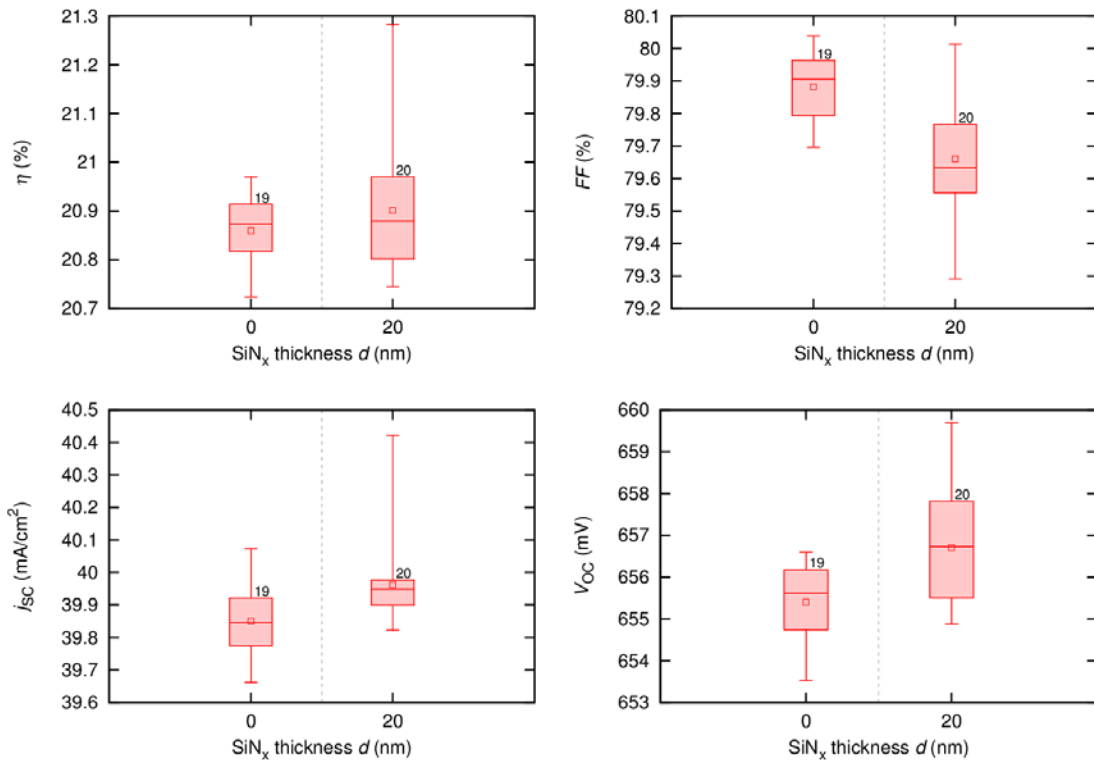


**Figure 3:** Measurement of the internal reflection  $R$  at the rear side, after foil attachment and laser fired contacts dependent on the  $\text{SiN}_x$  capping layer thickness. The reflection varies by  $< 0.5 \%$  in the IR regime.

The finished cells, with attached aluminium foil, are put into a climatic chamber to check if the capping layer has an additional protection function for the  $\text{Al}_2\text{O}_3$  passivation layer against outside influences, like temperature or humidity. The results of the accelerated aging, which is done by a damp-heat-test for 1000 h, are shown in Figure 4. The measured results from the I-V-measurement during the test are normalized, so the relative percentage loss can be seen very easily. The decrease in fill factor  $FF$  between the measurements across all groups can be explained by corrosion of the metallic contacts on the front and the rear side. Therefore this effect, which can be seen at the reference group 5 too, is not correlated to a degraded passivation. Group 1, without capping layer, is the only group that shows a significant decline in the efficiency mean value of  $\Delta\eta = -2.2 \%$  even after the first cycle (168 h). The reason for that is a decrease in  $j_{sc}$  and  $V_{OC}$ , as can be seen in Figure 4, due to a degraded passivation layer. After 672 h the loss increases up to  $-5 \%$  so far, which is the maximum value to pass the DH test. The efficiency of all other groups retain at a constant value. In fact the hydrogen from the  $\text{SiN}_x$  layer in combination with the temperature during the DH test leads to an annealing of the passivation, thus to a little increase in  $V_{OC}$  for all capped groups. As a consequence we can state, that a capping layer with  $d = 10$  nm is sufficient to protect the  $\text{Al}_2\text{O}_3$  passivation, so that no decrease in efficiency can be observed up to  $>670$  h so far.



**Figure 4:** Normalized I-V-measurement results of  $156 \times 156 \text{ mm}^2$  sized, PERC cells at various times of a 1000 h damp-heat-test (85 °C, 85 % humidity) so far, featuring different thicknesses of SiN<sub>x</sub> capping layers, starting from 0 up to 100 nm. The digit next to the bars indicates the number of cell in that particular group. The best cell has an efficiency of  $\eta = 19.17 \%$ .



**Figure 5:** I-V-measurement results of  $156 \times 156 \text{ mm}^2$  sized, mCz-Si PERC cells processed together with Roth & Rau, featuring two different thicknesses of SiN<sub>x</sub> capping layers, a double ARC layer and no busbars on the front side. The digit next to the bars indicates the number of cell in that particular group.

Afterwards highly efficient large area solar cells are produced, using the dielectric stack with no and 20 nm SiN<sub>x</sub> capping for the rear side. The cells are processed completely on Roth & Rau's pilot line, except for the rear side Al-foil metallization. Afterwards the I-V-measurement is performed by Roth & Rau, because of the non-busbar design on the front side and for this purpose needed special contact bars [7]. As can be seen in Figure 5 there is no difference in the mean efficiency of 20.9 % between both groups, as expected from the previous results. The best cell with 20 nm capping achieves a supreme efficiency  $\eta = 21.3$  %, because of a very high  $j_{sc}$  as a result of missing busbars, a double ARC layer on the front side and the increased internal reflection from the foil metallized rear side. Due to a low serial resistance of the Al-foil and thus to a high transverse conductivity the fill factor  $FF$  reaches a value of  $FF = 80$  % for the best cell. The serial resistance contribution of the rear side metallization, measured from busbar to busbar, is only  $9 \text{ m}\Omega\text{cm}^2$  using an Al-foil, compared to  $34 \text{ m}\Omega\text{cm}^2$  with a screen printed metallization, optimized for PERC solar cells with local contact openings (LCO). Based on a standard approximation [8], this effect leads to an improvement of approximately 0.1 %<sub>abs</sub> in  $FF$ .

#### 4 CONCLUSIONS

We demonstrate that the Al-foil based metallization features a process simplification potential using thinner dielectric layers besides the saving of metal consumption and the omission of one process step. Neither a loss in  $j_{sc}$ , in  $FF$  nor in  $V_{OC}$ , and therefore in efficiency, can be observed with thinner SiN<sub>x</sub> capping layers or even no capping. Only the damp-heat-test reveals that a very thin capping layer of 10 nm is sufficient to protect the Al<sub>2</sub>O<sub>3</sub> layer beneath from accelerated aging. Finally we report an efficiency of 21.3 % on large area, pilot line processed solar cells with an aluminium foil rear side metallization and a 20 nm SiN<sub>x</sub> capping layer but without busbars on the front side.

#### 5 ACKNOWLEDGMENT

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