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Increase the competitiveness of the EU PV manufacturing industry

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High-performance low-cost modules with excellent environmental profiles for a competitive EU PV manufacturing industry

HighLite- Deliverable report

D3.8. n-PERT cell with a top efficiency ≥23.0% on ¼ (or smaller) cut-cells.

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About HighLite

The HighLite project aims to substantially improve the competitiveness of the EU PV manufacturing industry by developing knowledge-based manufacturing solutions for high-performance low-cost modules with excellent environmental profiles (low CO_2 footprint, enhanced durability, improved recyclability). In HighLite, a unique consortium of experienced industrial actors and leading institutes will work collectively to develop, optimize, and bring to high technology readiness levels (TRL 6-7) innovative solutions at both cell and module levels.

HighLite consortium members

3D-Micromac, Applied Materials, CEA / INES, CSEM, EPFL, Fraunhofer ISE, Henkel, ibs Innovative Ion Implant, imec, ISC International Solar Energy Research Center Konstanz, ISFH, PI Berlin, Soli Tek, TNO innovation for life, University of Ljubljana, Valoe, Voltec Solar

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Dissemination level[2]

PU	**Public**	X
CO	**Confidential, only for members of the consortium (including the Commission Services)**	

[1] **Deliverable Type**
Please indicate the type of the deliverable using one of the following codes:
R Document, report
DEM Demonstrator, pilot, prototype
DEC Websites, patent fillings, videos, etc.
OTHER
ETHICS Ethics requirement
ORDP Open Research Data Pilot
DATA data sets, microdata, etc.

[2] **Dissemination level**
Please indicate the dissemination level using one of the following codes:
PU Public
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EU-RES Classified Information: RESTREINT UE (Commission Decision 2005/444/EC)
EU-CON Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC)
EU-SEC Classified Information: SECRET UE (Commission Decision 2005/444/EC)

Publishable summary

A major and ambitious objective of the HighLite project is to improve the efficiency of low-cost industrial Interdigitated Back Contact (IBC) solar cells from ~23% at the start of the project to ≥24.5% on full-size cells and ≥24.3% on ¼ (or smaller) cut-cell wafers by the end of the project. This requires the implementation of high-temperature passivating contacts, using industrial equipment and a lean process flow, that are compatible with screen-printing metallization. To fast-track developments, competing industrial approaches to form n^+ doped polysilicon-based (poly-Si) passivating contacts are being optimized in T3.3 using n-type Passivated Emitter and Rear Totally diffused (n-PERT) solar cells featuring a boron-diffused emitter at the front and screen-printed Ag contacts on both sides. Industrial approaches for the formation and patterning of n^+ and p^+ doped poly-Si passivating contacts are developed in parallel in T3.4. The most promising approaches are then used in low-cost industrial IBC cells also in T3.4 to reach the ambitious IBC cell efficiency targets by the end of the project.

In the previous (public) report D3.3 (n-PERT cell with a top efficiency ≥22.5%) we demonstrated efficiencies above 22.5% using pilot-production equipment available at imec and a relatively simple process flow based on ex-situ doped low-pressure chemical vapor deposition (LPCVD). We also showed that these high efficiencies levels were obtained by several of the partners involved in T3.3 using different deposition methods to form the n^+ poly-Si.

In this new (public) deliverable report D3.8, we report on further progress towards cell efficiencies above 23.0% on ¼ (or smaller) cut-cells. Achieving such efficiencies on cut-cells is particularly relevant to minimize subsequent interconnection losses and hence maximize module efficiencies which is key to improve the competitiveness of the EU PV manufacturing industry.

Contents

List of acronyms, abbreviations and definitions

Abbreviation	Definitions
Voc	Open circuit voltage (measured at cell level)
IBC	Interdigitated Back Contact
iVoc	Implied Voc (measured before metallisation)
Jsc	Short circuit current
FF	Fill Factor
Eta	Cell efficiency
r_c	Contact resistivity
J_0	Saturation current density. Can be on passivated or on metallised area
ALD	Atomic Layer Deposition
PECVD	Plasma Enhanced Chemical Vapour Deposition
PERT	Passivated Emitter and Rear Totally Diffused
LPCVD	Low Pressure Chemical Vapour Deposition
PL	Photoluminescence
TLM	Transfer Length Method
TOPCon	Tunnel Oxide Passivated Contact
SDR	Saw Damage Removal
BSF	Back Surface Field
TLS	Thermal Laser Separation
PET	Passivated Edge Technology

1. Introduction

This deliverable is part of Work Package 3 (WP3) which is entitled "Novel layers and processes implemented in existing solar cell pilot lines". WP3 comprises the following five tasks:

- T3.1: cell manufacturing in pilot lines
- T3.2: Optimization of industrial approaches to minimize cut-edge recombination losses
- T3.3: Optimization of industrial approaches for high-temperature passivating contacts
- T3.4: Implementation of high-temperature passivating contacts in IBC solar cells.
- T3.5: Evaluation of methods for testing and sorting of cut-cells

The approach in T3.3 is to optimize high temperature passivating contacts towards industrial implementation on large area textured substrates (6-inch) with a strong focus on compatibility with low-cost screen-printing metallization solutions. For simplification (no alignment patterning needed) and to avoid issues related to parasitic absorption, n^+ poly-Si passivating contacts are only integrated at the rear side of front-junction bifacial n-PERT cells. Leanings made in T3.3 are being continuously transferred to T3.4 where industrial approaches for the formation and patterning of n^+ and p^+ doped poly-Si layers are being developed to produce high-efficiency IBC cells with passivating contacts.

Deliverable D3.8 is part of T3.3 and follows the previous deliverable report D3.3 (n-PERT cell with a top efficiency ≥22.5%.) which was submitted at M18. Overall, the main objective of D3.8 is to demonstrate a bifacial n-PERT cell with an energy conversion efficiency of at least 23.0% on ¼ (or smaller) cut-cells.

Table 1: Overview of deliverable D3.8.

Deliverable Number	Short deliverable name	Lead beneficiary	Type	Dissemination level	Due date
D3.8	n-PERT cell with a top efficiency ≥23.0% on ¼ (or smaller) cut-cells.	IMEC	R	PU	M36

2. Work performed

2.1. Background information

High-temperature passivating contacts, which incorporate a thin tunnel oxide associated with a heavy doped polysilicon (poly-Si) layer to suppress recombination and promote charge carrier selectivity, offer a promising solution for the race towards high efficiency cells[3,4]. Today, most companies are focusing on the integration of poly-Si passivating contacts in n-PERT solar cells featuring a boron-diffused emitter at the front, n^+ doped poly-Si at the rear, and high-temperature screen-printing Ag metallization on both sides. The acronym TOPCon (Tunnel Oxide Passivated Contacts) is often employed across the PV industry for this type of industrial n-type solar cells. It became popular following the very rapid progress made by Fraunhofer ISE in the 2015-2020 period[5].

The industrial viability of different poly-Si deposition methods such as in-situ/ex-situ n^+ doped low-pressure chemical vapor deposition (LPCVD) or in-situ n^+ doped plasma-enhanced chemical vapor deposition (PECVD) available at the research institutes ISFH, ISC Konstanz, CSEM, imec, CEA INES, and Fraunhofer ISE was reported in D3.2 with the key results published in an open access journal paper[6].

In this work, the main attention will therefore be focused on an optimization of n^+ poly-Si passivating contacts on large area (6-inch) n-type Czochralski-grown (n-Cz) wafers using an approach based on Low Pressure Atmospheric Chemical Vapour Deposition (LPCVD) and ex-situ n^+ doping in a $POCl_3$ diffusion furnace. The LPCVD system used by imec is a pilot-production tool in which batches up to a few hundred wafers can be processed. Screen-printing metallisation using silver (Ag) pastes fired at high temperatures (700-800˚C) is also selected to meet industry needs for low-cost processing. Finally, the other process steps involved in the cell fabrication, such as p^+ emitter diffusion (in a BBr_3 tube furnace), rear side polishing, wet cleaning, ALD Al_2O_3 emitter passivation, and PECVD SiN_x are also executed in pilot-production tools (with manual loading) in imec's pilot line.

[3] M. K. Stodolny, M. Lenes, Y. Wu, G. J. M. Janssen, I. G. Romijn, J. R. M. Luchies, and L. J. Geerligs. "n-Type polysilicon passivating contact for industrial bifacial n-type solar cells." Solar Energy Materials and Solar Cells 158 (2016): 24-28. https://doi.org/10.1016/j.solmat.2016.06.034

[4] T.G. Allen, J. Bullock, X. Yang, A. Javey, and S. De Wolf. "Passivating contacts for crystalline silicon solar cells." Nature Energy 4, no. 11 (2019): 914-928. https://doi.org/10.1038/s41560-019-0463-6

[5] SW Glunz, Steinhauser B, Polzin JI, Luderer C, Grübel B, Niewelt T, Okasha AM, Bories M, Nagel H, Krieg K, Feldmann F. Silicon-based passivating contacts: The TOPCon route. Progress in Photovoltaics: Research and Applications. 2021 Dec 20. http://dx.doi.org/10.1002/pip.3522

[6] T. Fellmeth, Feldmann F, Steinhauser B, Nagel H, Mack S, Hermle M, Torregrosa F, Ingenito A, Haug FJ, Morisset A, Buchholz F. A round Robin-Highliting on the passivating contact technology. Epj Photovoltaics. 2021;12:12. https://doi.org/10.1051/epjpv/2021011

2.2. Results obtained

2.2.1. Solar cells results obtained at imec

In the latest batch 100 Topcon cells were produced, evaluating 2 metallization pastes (A/B, each 50 cells), and using firing temperature (825, 840, 855 and 870 °C) as optimization parameter. The buildup and resulting front and rear appearance is shown in Figure 1.

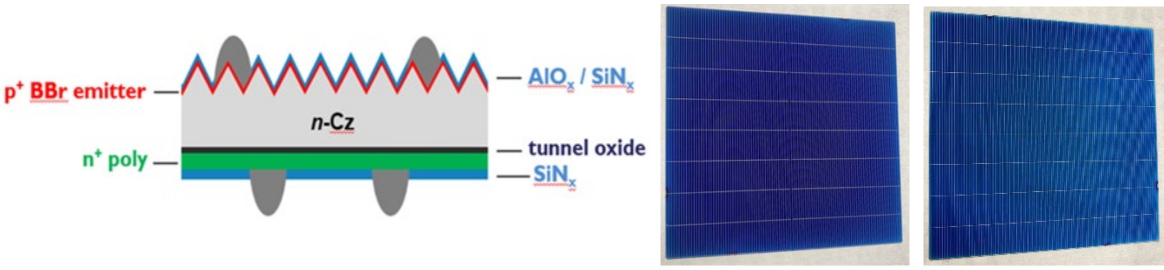

Figure 1. (Left) Cross-section buildup and (middle) front and (right) rear impression of the produced cells

The busbarless cells were measured using a multi-wire GridTouch™ contacting chuck. Figure 2 shows the IV-results for paste A. The large spread in performance for the cells fired at 870 degC points towards overfiring, while the average efficiency for the best group of 13 cells (fired at 840) amounts to 23.0% (imec internal measurement). Also the spread in performance is lowest for this group.

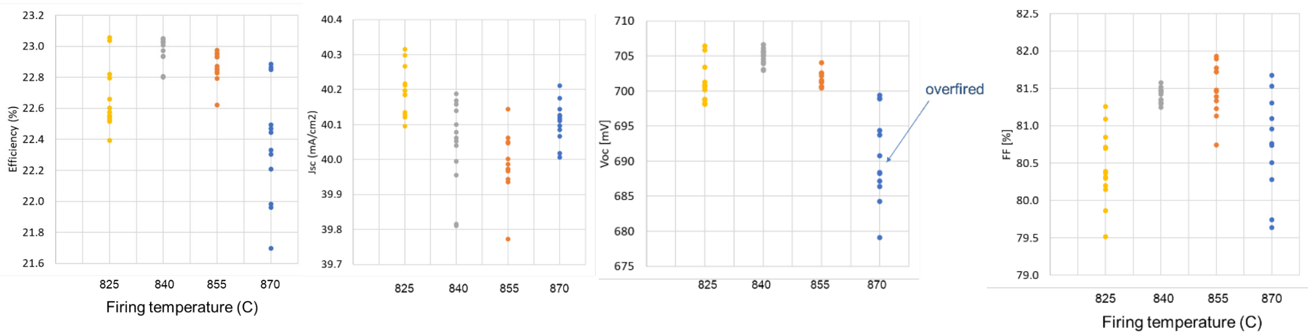

Figure 2. I/V parameters of bifacial Topcon solar cells using metallization paste A with varying firing temperature

Figure 3 shows the IV-results for paste B. Here the performance is slightly lower, yielding an average efficiency for the best groups (fired at 825 and 840C) of 22.7%, and overall more spreading is observed compared to the paste A results.

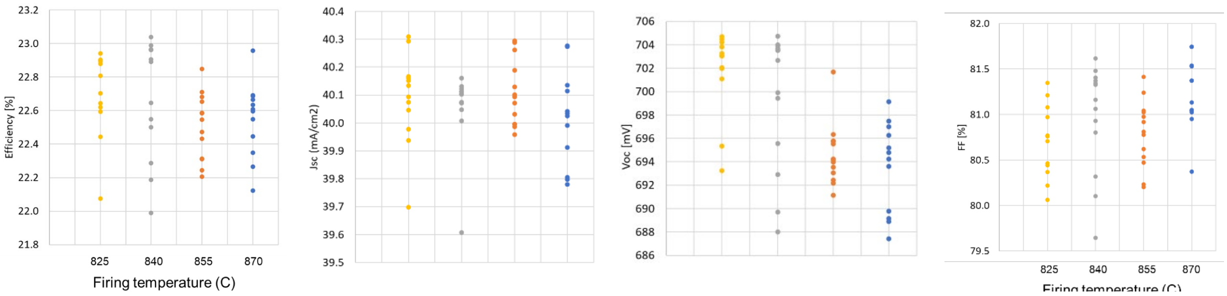

Figure 3. I/V parameters of bifacial Topcon solar cells using metallization paste B with varying firing temperature

Afterwards, the ~50 paste A cells were sent to Fraunhofer-ISE for the cutting and repassivation process, including characterization before and after.

2.2.2. Cutting and repassivation at Fraunhofer-ISE

The above cells were cut using 3D-Micromac's TLS-technology (Thermal Laser Separation: combining laser-based heating and water-spray cooling) and repassivated with PET[7] (Passivated Edge Technology: AlO_x deposition and annealing) at Fraunhofer ISE.

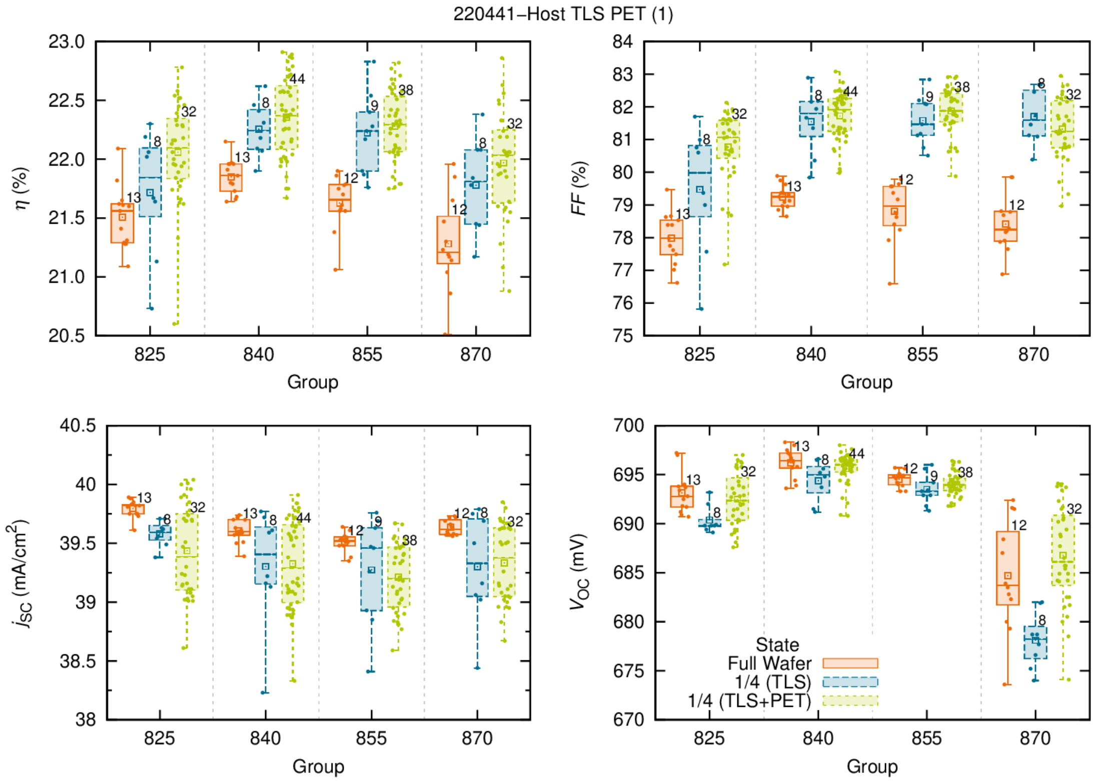

Figure 4. I/V parameters of bifacial Topcon solar cells before cutting (full wafer), after cutting (1/4 TLS) and repassivation (1/4 TLS+PET).

In Figure 4 the IV data of four groups (825, 840, 855 and 870) are shown. The increase of the fillfactor (FF) after cutting (TLS) was not expected but could be due to the different contacting method for the IV measurements (GridTouch™ for the full wafers and like a three-busbar configuration for the cut cells). For the IV measurements of the cut cells (after TLS and after TLS+PET) the same method for contacting was used. Therefore, these results are directly comparable. For all groups shown in Figure 4 an increase in efficiency η after PET could be observed. The highest efficiency (after TLS+PET) was measured in group 840 with η = 22.9%. In average the efficiencies of this group were between 22.0-22.4%. The results confirm former investigations (presented at the GA06 in Vilnius, 2022), that at least an improvement of $\eta_{abs.} = 0.2\%$ is possible with PET for TOPCon cells (1/6th, G1).

[7] P. Baliozian et al., "Postmetallization "Passivated Edge Technology" for Separated Silicon Solar Cells," in IEEE Journal of Photovoltaics, vol. 10, no. 2, pp. 390-397, March 2020, doi: 10.1109/JPHOTOV.2019.2959946.

3. Conclusions

In this report, we have presented the results obtained at imec on further improving the process reported in D3.3. Here, 2 metallization pastes were evaluated and the firing temperature was screened in a batch of 100 TOPcon cells. This way, we could demonstrate an average cell efficiency of 23.0% for the best group with 13 cells reaching the target efficiency. Additionally, these solar cells were cut in ¼ cells by using TLS and repassivated with PET at Fraunhofer-ISE. With this method, the best ¼ cells reached efficiencies up to 22.9%, very close to the targeted 23% and showing almost no loss compared to the uncut cells. We therefore consider this deliverable as achieved.