SOLAR-ERA.NET

Cofund

Transnational Project

"PEarl"

End Report

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General Project Information

Project acronym: PEarl
Project title: „PERC meets self-aligned selective emitter technologies based on inkjet printing and silver less plating”
Project number: SOLAR-ERA.NET Cofund 1 N° 026
Project number RVO: TESOL17005
Project website: n.a.

Start date of the project: *01.01.2018*
End date of the project: 30.09.2020 (after project extension)

End Report
Report date: *8.03.2021* *(Period to be reflected since the Mid-term Report: 31.12.2019 – 30.09.2020)*

Total project costs (EUR): 1050.000,00
Requested funding budget (EUR): 676.000,00

Coordinator contact details:

Short name of organisation	Fraunhofer ISE
Full name of organisation	Fraunhofer Institute for Solar Energy Systems
Department of organisation	Division Production Technology: Structuring and Metallization
Type of organisation*	Public research organisation
First and family name of coordinator	Roman Keding, Raphael Efinger
Full address	Heidenhofstrasse 2, 79110 Freiburg
Country	Germany
E-mail	roman.keding@ise.fraunhofer.de raphael.efinger@ise.fraunhofer.de
Phone number	Roman Keding: +49(0)761/4588-5827 Raphael Efinger: +49(0)761/4588-5535
PIC (9-digit Participant Identification Code)	999984059

Consortium Partner 2 contact details

Short name of organisation	Meyer Burger
Full name of organisation	Meyer Burger (Netherlands) B.V.
Department of organisation	Business Unit Printing
Type of organisation*	Private – SME
First and family name of coordinator	Mr Joost Hermans
Full address	Luchthavenweg, 10, 5657EB Eindhoven
Country	Netherlands
E-mail	Joost.Hermans@meyerburger.com
Phone number	0031 611566280
PIC (9-digit Participant Identification Code)	953146348

Consortium Partner 3 contact details

Short name of organisation	SUN Chemical
Full name of organisation	Sun Chemical Ltd. - Global Electronic Materials Technology
Department of organisation	Electronic Materials / Digital Applications
Type of organisation*	Private - LE
First and family name of coordinator	Mike Pickrell
Full address	Norton Hill, BA3 4RT Midsomer Norton
Country	United Kingdom
E-mail	Mike.Pickrell@sunchemical.com
Phone number	0044 01761 408655
PIC (9-digit Participant Identification Code)	951094022

Consortium Partner 4 (Observer, not funded) contact details

Short name of organisation	RENA
Full name of organisation	RENA GmbH
Department of organisation	R&D Manager Back End & Technology
Type of organisation*	Private - LE
First and family name of coordinator	Damian Pysch
Full address	Hans-Bunte-Strasse 19, 79108 Freiburg
Country	Germany
E-mail	Damian.Pysch@rena.com
Phone number	0049 7611506340
PIC (9-digit Participant Identification Code)	983906406

Number of researchers involved and jobs created

Total number of researchers involved	**Number of young researchers involved**	**Number of female researcher involved**	**Number of permanent jobs created**	**Number of temporary jobs created**
12	**5**	**2**	**0**	**0**

Verwijzing naar Ministerie van Economische Zaken en Klimaat (EZK):

Dit project werd uitgevoerd met subsidie van het Ministerie van Economische Zaken en Klimaat

Publishable Project Summary

The project focus is set on the exploitation of selective emitter’s potential in passivated emitter and rear contact (PERC) silicon solar cells. Compared to PERC solar cells with a homogeneous emitter, those with selective emitter predict a significant increase in conversion efficiency of at least 1.0% absolute and, in consequence, would drastically increase the yield of PV systems, decrease the levelized cost of electricity, and the total cost of ownership. Therefore, Fraunhofer ISE, Meyer Burger, RENA, and Sun Chemical mix together their complementary competences in the fields of solar cell processing, machine engineering, and material synthesis in order to evaluate self-aligned process techniques based on the steadily advancing inkjet and plating technology, whereby low Ag consumption is aimed at. The techniques of interest will be applied, validated and demonstrated in the PV-TEC or comparable on pilot-line scale. The high innovation of the addressed technologies, the potential of selective emitters in PERC solar cells also with regard to low-cost PV-manufacturing, as well as the technology readiness level – which ranges between TRL4 and 6 – lead to the conclusion that the project’s outcome will provide a competitive solar cell technology for the PV-market with a high potential of being quickly transferred into PV-fabs, which would be connected to a high benefit for all involved European stake- and shareholders.

General conclusion

After completing the milestones and deliverables from workpackages 2, 3, 4 and 5 the complete process flow has been implemented in workpackage 6, showing functional solar cells for both process routes.
For process route 1, a maximum efficiency of 21.7% and a gain of $\Delta\eta$ = 0.16%abs. in efficiency (group 2) could be demonstrated compared to its homogeneous emitter counterpart (group 1) mainly attributed to the gain in open circuit voltage (VOC).
For process route 2, all single processes, partially developed on small wafer sized samples, were combined and implemented into the full PERC process flow in ISE’s pilot-line with industrial-size wafers and industrially relevant equipment. Finally, an efficiency of 19,89% could be demonstrated for this self-aligned, challenging, but innovative process route. For process route 2 the COGS (Cost of Goods Sold) of the complete cell process are 26.20€ct/cell, where there is a high potential to decrease the total costs by optimizing alkaline texturing and cleaning. With this COGS the PEarl process requires 0.4% efficiency gain on TCO level (Total Cost of Ownership for module manufacturing) and even less than 0.2% on LCOE level (Levelized Cost of Energy).
The results from the PEarl project have been presented at conferences in Europe and Asia.

Summary on Project Progress

The following Gantt chart shows the original or rather initial time schedule (highlighted in blue) and the updated project schedule (highlighted in orange) after project extension. After a fire incident at Fraunhofer ISE, occurred in February 2017, which caused the total loss of all equipment within the laboratory, the new laboratory has been completed since March 2018 and systems have been gradually introduced and put into operation. Nevertheless, installation and commissioning of several core systems important for the project Pearl as for example diffusion furnace, wet chemical systems and the automated inspection system were severely delayed by several months. Therefore, in April 2019 the project consortium successfully requested a cost-neutral project extension for additional 9 months.
The colour code (green/red) corresponds to the final status of each work package at the end of the project (month33). More details about the single work packages and their final status in respect to the updated project schedule can be found in the next section of this report.

At the end, 18 (81,81%) out of 22 work packages are completely fulfilled, three (13,63%) are partially fulfilled and one (4,54%) is not fulfilled.

WP	Task	Title	January 2018	February	March	April	May	June	July	August	September	October	November	December	January 2019	February	March	April	May	June	July	August	September	October	November	December	January 2020	February	March	April	May	June	July	August	September 2020
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1		**Administration**	x	x	x	x	x	x	x	x	x	x	x	D	x	x	x	x	x	x	x	x	x	x	x	D	x	x	x	x	x	x	x	x	D
	1,1	Coordination	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	1,2	Reporting	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2		**Material Synthesis**	x	D	x	M	x	D	x	x	x	x	x	x	x	x	x	x	x	x	x	M	x	x	x	x	x	x	x	x	x	x	x	x	x
	2,1	Development of Hotmelt inks	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	2,2	Development of alternative inks									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3		**Alignment**	x	x	x	x	x	x	x	x							x	x	x	M	x	x	x	x	x	M									
	3,1	Data gathering by high-resolution camera	x	x	x	x											x	x	x	x	x	x													
	3,2	Data analysis			x	x	x	x										x	x	x	x	x	x												
	3,3	Evaluation of alignment accuracy	x	x	x	x	x	x	x	x										x	x	x	x	x											
	3,4	Compatibility with mass production					x	x	x	x							x	x	x	x	x	x	x	x	x	x									
4		**Mask&etch processing**	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	M	x	M	x	x	x	x	x	x	x				
	4,1	Development of printing strategies	x	x	x	x	x	x	x	x							x	x	x	x	x	x													
	4,2	Inkjet printing			x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x										
	4,3	Etching					x	x	x	x	x	x					x	x	x	x	x	x	x	x	x										
	4,4	Stripping							x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x							
	4,5	Lift-Off							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
5		**Pre- and Post-Processing**			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	M	x	D	x	M	x	x	x	x	x				
	5,1	Emitter formation			x	x	x	x	x	x	x	x					x	x	x	x	x	x	x	x	x										
	5,2	Passivation							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x							
	5,3	Metallization									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
6		**Solar cell and module processing**									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	M	x	x	x	M,D	x	D	x
	6,1	Small-volume production									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
	6,2	High-volume production (>100 wafer/batch)															x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
	6,3	Solar cell characterization											x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
7		**Simulation**					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	7,1	Grid simulation by GridSim					x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x									
	7,2	Loss Analysis by Sentaurus Device										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
8		**Economical evaluation**	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

x	Original time schedule/ Ursprünglicher Zeitplan		accomplished/erfüllt
x	Original time schedule/ Ursprünglicher Zeitplan		Partially accomplished/teilweise erfüllt
x	Updated time schedule/ Neuer Zeitplan	M	Partially accomplished/teilweise erfüllt
x	Updated time schedule/ Neuer Zeitplan	M	Not accomplished/ nicht erfüllt

Figure 1 Gantt chart – Final status of project progress

Has there been any changes in the	No	Minor	Substantial
Consortium composition?	x		
Work progress?		x (after extension)	x (before extension)
Expenses (vs budget)?	x		

Work Progress

Further details about the milestones can be found under the section “Results and Impact”.

List of Milestones (to be continued and completed year by year)

Milestone number	**Milestone title**	**Scheduled in project month**	**After project extension**	**Achieved in project month**	**Further information**
M2.1	**Ink with printed features below 60 µm**	**4**	**-**	**4**	Milestone is achieved and presented within start report.
M2.2	Ink compatible with PECVD & Lift-off process	**12**	**20**	**20**	Milestone is achieved
M3.1	**Data Gathering**	**4**	**18**	**18**	Milestone is achieved
M3.2	**Alignment accuracy**	**8**	**24**	**24**	Milestone is partially achieved
M4.1	**Inkjet process incl. mask&etch with printed features below 45 µm**	**8**	**20**	**24**	Milestone is achieved.
M4.2	**Doped regions below 45 µm & controllable etch-back process**	**12**	**22**	**30**	Milestone is achieved
M5.1	**Passivation quality of selective emitter structure**	**12**	**20**	**20**	Milestone is achieved
M5.2	**Process sequence for selective emitter technology**	**16**	**24**	**26**	Milestone is achieved
M6.1	**Successful implementation into process sequence of PERC solar cells.**	**16**	**26**	**32**	Milestone is partially achieved
M6.2	**The high-volume production of solar cells based on the designated vehicle.**	**22**	**30**	**n.a.**	Not completed

Deliverable number	Deliverable title	Scheduled in project month	After project extension	Achieved in project month	Further information
D1.1	Annual report 2018	0	-	8	Start report (month 1-8)
D1.2	Annual report 2019	24	24	26	Mid-term report (month 9-24)
D1.3	Final report 2020	-	33	n.a.	End-term report (month 25-33)
D2.1	Inks for the evaluation of doping patterns (WP4)	2	-	2-20	Several iterations. Final ink formula in month 20
D2.2	Inks for the evaluation of doping and self-aligned metal patterns (WP4)	6	-	6-24	Several iterations. Final ink formula in month 24
D5.1	Selective emitter technology (Front-End) for solar cell processing (WP6)	8	22	26	Completely achieved.
D6.1	4 PERC Cells with efficiency of 22 % for module integration (WP6)	18	32	n.a.	Not achieved due to missing Milestone M6.2
D6.2	Demonstrator mini-module featuring 4 PERC cells with selective emitter	22	33	n.a.	Not achieved due to missing Milestone M6.2

WP1 Administration – complete
Overall management of the project (WP description & progress)
WP1.1 Coordination → complete
WP1.2 Reporting → complete

In total two project meetings and monthly telephone conferences took place within month 25 to 33 to assure a close collaboration of the project partners and a constant exchange of information and results. Moreover, several bilateral telephone conferences and video conferences between selected partners were conducted, in order to focus specific scientific and technological questions.

WP2 Material Synthesis – complete
Synthesis of inkjet printable materials compatible to the full process sequence
WP3.1 Development of hotmelt inks → complete
WP3.2 Development of alternative inks → complete

There has been a steady supply of inks by the project partner Sun Chemical to Fraunhofer ISE for evaluation according to process and solar cell performance parameters. Thus, several batches of hotmelt inks for mask&etch has been designed, supplied and evaluated regarding their printability, printed feature size and their chemical resistance against two etch-back solutions. The best performing ink is **U11912** allowing narrow printed feature sizes below 40 µm and sufficient chemical stability against a HF-HNO_3 (Hydrofluoric -Nitric acidic solution) based etch-back solution with perfect congruency of printed (mask) and selective emitter (after etch-back) pattern, whereas a negative interaction of the hotmelt ink can be observed with a HF-Persulfate (Hydrofluoric-Peroxodislfuric acidic) based etch-back solution.

Several batches of UV (Polymer)-Hotmelt based inks have been designed, supplied and evaluated regarding their printability, printed feature size and their chemical and thermal resistance. Ink **U12445** successfully demonstrate the general feasibility to all single process steps as etch-back, PECVD (plasma enhanced chemical vapour deposition) up to 300°C, lift-off and plating into the opened areas after lift-off.

Both ink types are implemented using their corresponding process route (see Appendix) within a PERC (passivated emitter and rear cell) process sequence in order to demonstrate the general feasibility of those inks in the full process sequence.

WP3 Alignment – Complete

Development of alignment strategy for the production of PERC solar cells. The aim is to optimize the alignment of the inkjet and screen printing processes by compensating for the screen distortion caused by the screen printing process by adapting the digital image of the inkjet printer using image recognition and software algorithms in order to match the screen printing pattern.

WP3.1 Data gathering by high resolution camera → complete

WP3.2 Data analysis → complete

WP3.3 Evaluation of alignment accuracy → complete

WP3.4 Compatibility with mass production → complete

Within this work package an AOI-system (automated optical inspection system) was used for the data gathering of the screen printed pattern. Due to delay in installation and hook-up of such a system, which is implemented into a fully industrial metallization line, an alternative solution using a stand-alone coordination measurement system was used until July 2019. With the final objective in mind, the work-around solution was used to start developing an automated algorithm procedure for data analysis and an alignment accuracy of ±15 µm could be demonstrated. In the second half of 2019, the process was transferred to an AOI system implemented into the cell testing unit instead of the metallization line due to synergies with other projects as well as the simpler built-up of the system allowing a quicker implementation of the alignment strategy but sacrificing in image resolution and, therefore, in the final accuracy. With this AOI system, the image resolution is restricted to 2540 dpi, leading to a Pixel size of 10 µm.

The full alignment strategy with (1) image recognition, (2) algorithm to compensate for errors caused by camera and optics, (3) extraction of the coordinates of the screen-printed pattern, (4) creating inkjet image and (5) printing the inkjet image onto the screen-printed metallization layout was tested. The first analysis demonstrates an alignment accuracy of ±25 µm, which is inferior to the coordinate measurement system due to the lower accuracy of the image recognition (10 µm (AOI) versus 1µm (coordinate measurement system)), but allows a significant reduction of process time from several hours down to a few minutes.

The transfer of the alignment strategy into a final PERC cell batch with a wafer number of 32 pieces with varying selective emitter structures of 100, 160 and 210 µm in width was successfully realized with a metallization pattern by screen-printing using a finger width of 30 µm using the above described alignment method, thus, demonstrating an alignment accuracy of ±35 µm if implemented into a PERC solar cell. The inferior result was caused by an improper calibration of the automated inspection system leading to an increased error extracting the coordinates of the screen-printed pattern.

WP4 Mask&Etch processing – complete

Development of precise inkjet printing processes and thus the basis for high-resolution selective emitters. In addition, special inks are evaluated with regard to their temperature stability and thus their suitability in lift-off techniques.

WP4.1 Development if inkjet strategies → complete
WP4.2 Inkjet Printing → complete
WP4.3 Etching → complete
WP4.4 Stripping → complete
WP4.5 Lift-off → complete

The delivered inks were evaluated regarding their printability, printed feature size, their chemical resistance against the etch-back solution and, in case for the UV inks, for their thermal resistance against a subsequent PECVD deposition and the Lift-off process. The single processes of this revolutionary process approach have been successfully demonstrated within PEarl.

Hotmelt Inks

Printability was evaluated using the final printing setup *(print-head, printing system, substrate)*.
Printed feature sizes below 40 µm were achieved for several hotmelt inks. Despite promising initial results using a HF-persulfate *(Hydrofluoric-Peroxodislfuric acidic)* etch-back solution, this process has not been successfully integrated into a PERC cell technology due to negative influences of the ink on the etch-back process. Therefore, a HF-HNO_3 (Hydrofluoric -Nitric acidic solution) based etch-back solution was tested. This etch-back solution led to a porosification of the silicon surface which could be removed in a subsequent, lowly concentrated *(>0,5%)* potassium hydroxide solution. Generally, the latter step not only selectively removes the porous Si layer from crystalline silicon but also can be used to strip the hotmelt ink from the surface, which is considered the preferable method in production compared to a solvent based approach, due to the easier handling of the chemistry and safety.

UV-Hotmelt Inks

For further optimization of the printing results, a UV-LED unit was implemented into the print-head assembly in order to optimize the printing resolution by avoiding ink bleeding through direct pinning of the ink during printing. In close collaboration with Sun Chemical and Meyer Burger and several iterations of UV-Hotmelt inks, a suitable ink formula could be identified allowing narrow line-with of down to 40 µm, showing sufficient stability against the HF-HNO_3 based etch-back solution, and a sufficient thermal stability of up to 300°C PECVD deposition temperature. Finally, a process sequence could be found which enables a thermally triggered lift-off process a temperature of 600°C. Despite minor ink residues at the printed line edge after lift-off, successful Ni/Cu/Ag plating into the opened areas could be demonstrated. The issue of ink residues at edges of the opened areas could be solved by mechanical ablation with nitrogen convection.

We demonstrated the general feasibility of both ink types for PEarl processing and successfully implemented them using their corresponding process route (see Appendix) within a PERC (passivated emitter and rear cell) process sequence. Homogeneous process results could be demonstrated for each process step (inkjet printing, etching, stripping and lift-off) on industrial-size wafers – in fact M2 (156,75x156,75 mm).

WP5 Pre- & post processing – complete
Development of preliminary and subsequent processes for the implementation of new process modules (e.g. mask&etch, adapted PECVD and lift-off processes) into process sequence of the PERC solar cell.
WP5.1 Emitter formation → complete
WP5.2 Passivation → complete
WP5.3 Metallization → complete

Simulations for emitter formation were done in order to determine an optimum diffusion profile (dopant concentration vs. diffusion depth) of the phosphorous dopant. For the final PERC cell batch, a standard emitter profile was adapted in order to match the results of the simulation.

In order to develop a working process flow using an inkjetable polymer and Lift-off process, certain boundaries apply to the anti-reflective SiN_x coating. Main limitation is the thermal budget of the PECVD process defined by the ink formulation. Therefore, a DOE experiment (Design of Experiment) was performed in order to evaluate the main influence factors on the optical and electrical properties. The ink showed a sufficient thermal stability of up to 250°C during PECVD deposition. Higher temperatures are possible but would cause a degradation of the ink structure with negative impact on the Lift-off process. A SiN_x layer with very good optical (n=1.98, k= 0.039) and electrical properties (673 mV) on industrial precursors with minor losses in iV_{OC} of -0.9%$_{rel}$ compared to high temperature SiN_x was developed. Moreover, in plating experiments for deposition of Ni/Cu/Ag, it could be found that the “low-termperate” SiN_x layers do not suffer from parasitic deposition in defects like “ghost plating”. This effect was expected to be very critical.

Finally, all gathered results and optimizations were implemented within a PERC (passivated emitter and rear cell) process sequence using their corresponding process route (see Appendix) and compared to their standard process counterparts without a selective emitter structure. Even tough appealing results are achievable by a low temperature PECVD (plasma enhanced vapor deposition) passivation scheme (plasma oxide + silicon nitride; ≤300°C), it was not possible to match the passivation quality of their high temperature counterparts, typically a passivation stack (thermal oxide, 700°C + PECVD; 400°C), thus leaving the passivation as the main lever to further enhance the challenging process route 2. Further investigation is necessary to evaluated alternative deposition technologies as for example atomic layer deposition, which allows process temperatures below the thermal threshold of 300°C set by the thermal stability of the polymer ink system used.

WP6 Solar cell and module processing – partially complete
Based on the knowledge gained, PERC solar cells with a selective emitter are manufactured in small and large series.
WP6.1 Small volume production → complete
WP6.2 High-volume production → not completed
WP6.3 Solar cell characterization → partially completed

In the first half year 2019, a cell batch based on process route 1 (see appendix) and the HF-Persulfate etch-back solution was performed. Even though the selective emitter groups show lower efficiencies than the reference group with homogenous emitter, characterizing the full process sequence led to valuable information for further process developments in WP3, WP4, and WP5.

In the first half year 2020, a major cell batch including both process routes was planned and performed implementing the findings of process developments in WP3, WP4, and WP5 into the full process flow and addressing open questions raised from the gathered experience so far.

- Selective Emitter based on mask&etch + hotmelt ink + screen printing metallization (P1)
- Self-aligned emitter based on mask&etch + PECVD + lift-off + plating (P2)
- Optimizing emitter formation
- Evaluation of alignment strategy within cell batch
- Evaluation & up-scaling of $HF:HNO_3$ based etch-back solution
- Further optimization of cleaning & passivation process of plating groups
- Further optimization and up-scaling of lift-off and plating process

All developed processes were successfully implemented and upscaled to an industrial wafer size M2 (156x156 mm) by using industrially relevant equipment and, thus, the general feasibility of the PEarl process routes for PERC manufacturing could be demonstrated.
For process route 1, an efficiency improvement compared to a reference group with homogeneous emitter could be demonstrated.
For the more challenging process route 2, where a self-aligned selective emitter structure is utilized, all newly developed and adapted process were combined for the first time with appealing results, however, still not matching their counterparts from process route 1, but with high potential to further improve the efficiency.
A brief overview about the experiments with its main results can be found under section “Results and Impact”.

Due to time constrains caused by the pandemic spread of SARS-CoV-2 throughout 2020, the timeline of the first experiment was severely delayed and an additional iteration to further improve and optimize the process sequence for both process routes within a high volume cell batch (>100 wafer) had to be skipped. Therefore WP6.2 was not completed. As a consequence, also the milestones M6.1 and M6.2 as well as the deliverables D6.1 and D6.2 werde not completed.

WP7 Simulations – partially complete
Carrying out simulations to determine the ideal cell architecture and to estimate the efficiency potential
WP7.1 Grid simulation by GridSim → partially completed
WP7.2 Loss analysis by Centaurus device → partially completed

Simulations regarding emitter formation were carried out and serve as “objected concentration profile” for further process adaption towards higher conversion efficiency.

GridSim simulations were done in parallel in order to determine the optimum metallization layout for cells with and without selective emitter.

A detailed characterization and loss analysis was performed based on the quality parameters of the final cell batch, but a full device simulation using Centaurus was skipped. The resources were unutilized to further improve the performance of the significant, single processes, which was assumed to be of higher priority compared to a full device simulation, which is of higher relevance at fine tuning of performance parameters.

WP 8 Economical evaluation – complete
Presentation of the competitiveness of the developed technologies on the PV market.

The economic evaluation of the PEarl technologies based on inkjet with innovative inks is of utmost importance to attract potential investors. Therefore, a sophisticated tool was used (sCost*) to analyse the costs of ownership for single processes as well as for the entire process sequence. The models based on Perl processes were implemented and updated with the latest input parameters from the industrial partners.

Results on total cost of ownership (TCO) and levelized cost of electricity (LCOE) as major commercial decision criteria or rather parameter will be shown in section “Results and Impact”.

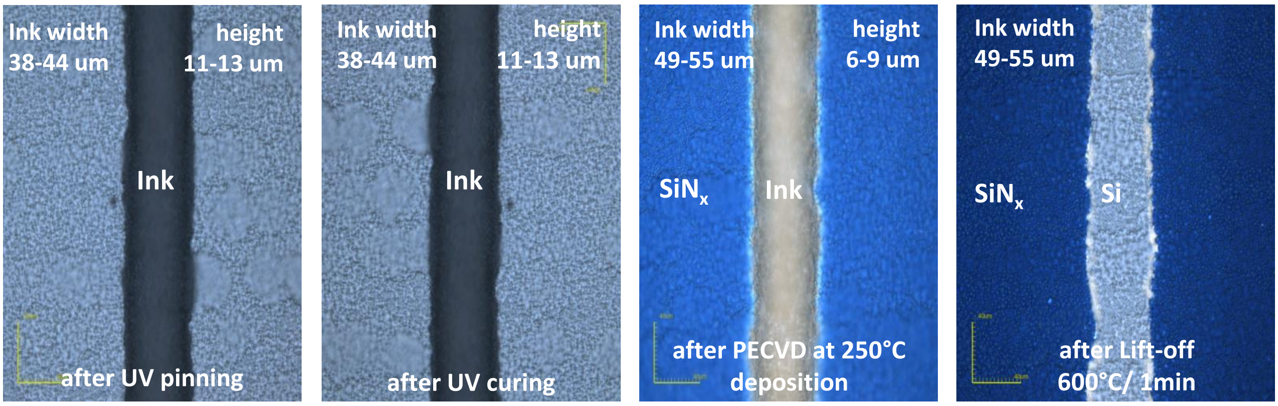
*Nold, S. et al. Cost Modeling of Silicon Solar Cell production innovation along the PV value chain, Proc. of the 27th EU PVSEC (2012) Frankfurt, Germany, pp. 1084-1090

Results and Impact

Milestone 2.2 → complete

Development of an alternative ink completed which enables sufficient temperature stability during PECVD and lift-off.

The figures below show microscopic images of the UV-hotmelt ink U12445 after different process steps indicating sufficient thermal stability during PECVD processes with deposition temperature of up to 300°C with a subsequent lift-off process at 600°C. After printing, a line width of below 45 µm could be achieved. A minor increase in linewidth during the PECVD process can be observed while line height is decreasing, but still maintaining 93% of the cross-section's area prior to the deposition process.



Parameter	Width [µm]	Height [µm]	Cross section [µm²]	Cross section [%]
Pinned	40.818 ± 2	11.84 ± 1	431.949	
Cured	40.486 ± 2	11.393 ± 1	433.362	100.00%
PECVD 200°C	50.52 ± 2	10.085 ± 1	413.157	95.34%
PECVD 250°C	51.52 ± 2	9.573 ± 1	404.321	93.30%
PECVD 300°C	49.315 ± 2	8.63 ± 1	398.362	91.92%
PECVD 380°C	44.315 ± 2	7.93 ± 1	231.613	53.45%

Even higher deposition temperatures of up to 380°C, which matches typical deposition temperatures of production tools and, therefore desired for an easy process transfer to a possible client, are in principle possible, but it comes with a negative impact on the lift-off process, resulting in longer process times and a higher amount of residues at the edges.

Milestone 3.1 → complete

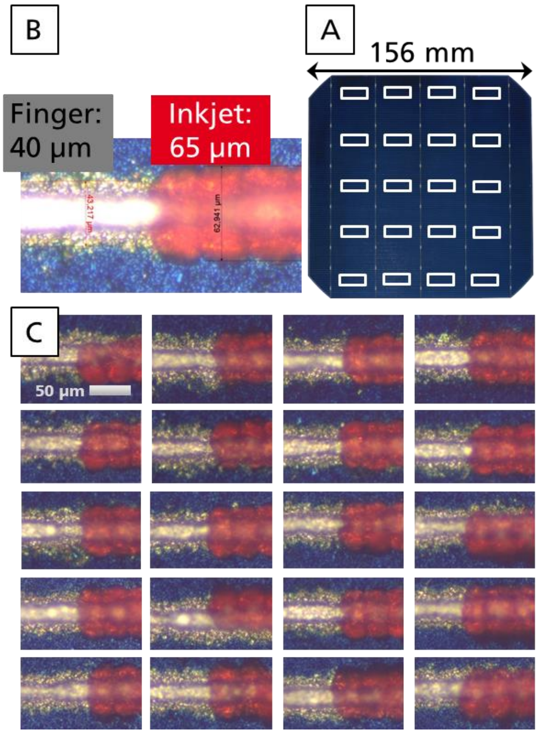
Imaging of screen-printed templates by high-resolution line-scan camera successfully completed. Successfully completed means the shot of electronic images indicating the warping of screen-printed patterns with a resolution of 5080dpi.

After implementation and commissioning of an in-line AOI system within the metallization line of Fraunhofer ISE in the pilot-line, high resolution images of 5080dpi could be extracted. Thus, the gathering of data directly after the screen-printing process with high resultion (5µm) was found out to be technically feasible. Nevertheless, to reach such high image resolutions, the system contains 2 cameras and optics making this system more complicated than a similar AOI tool (1 camera & optic, 2540 dpi) within the cell testing unit. Therefore, all PEarl-activities were shifted to the latter AOI tool in order to use synergies to other ongoing projects and to save resources for the other work packages within the project.

Milestone 3.2 → partially complete

Evaluation of alignment accuracy completed. The warping of the screen-printed images are considered in the digital pattern of the inkjet printer. The developed alignment strategy based on the high-resolution line scan camera enables a patterns’ congruency of ±5 µm between metal and ink upon an industrial-size wafer (243.23 cm squared).

(A) Printed wafer with screen printed layout. The white frames correspond to the measurement positions shown in C.
(B) Microscope images of the screen-printed layout (left) and the correspondingly created and printed inkjet structure (right)
(C) Various microscope images to check the alignment accuracy over the wafer surface



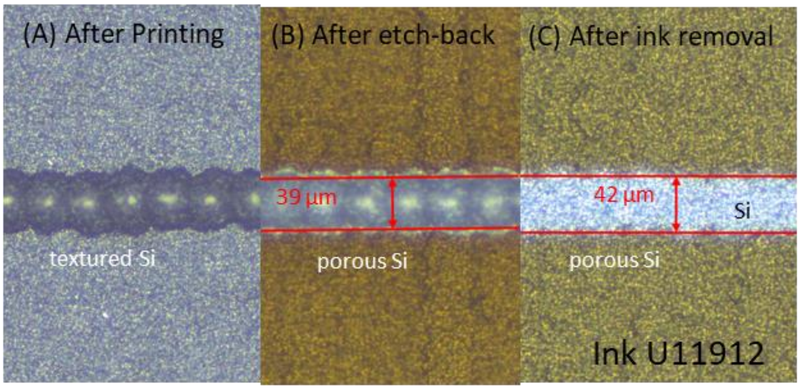
With a coordinate measurement system an alignment accuracy of ± 15 µm over the full wafer area could be achieved. The alignment strategy was then transferred to an AOI (automated inspection system) system. Within this AOI system, the image resolution has been restricted to 2540 dpi, leading to a Pixel size of 10 µm. Therefore, the alignment accuracy over the full wafer area was found out to be ± 25 µm. It has to be considered that the overall alignment accuracy depends on the sum of all possible errors using such an alignment strategy as for example accuracy of the printing systems including their image recognition of the alignment fiducials, accuracy of the AOI system and its image resolution etc..
This alignment procedure based on the AOI system was also used in the final cell batch, where an alignment accuracy of ± 35 µm was achieved over all processed wafers. This was not matching the results obtained in pretesting on single wafers. The main reason was an improper calibration of the AOI system. Already minor calibration fails led to an increase in accuracy compared to the procedure with the coordinate measurement system and underlines the complexity of all steps and systems involved to achieve a high alignment accuracy.

In conclusion, we successfully demonstrated a semi-automated alignment strategy between screen- and inkjet- printed patterns over a full-sized wafer of 156x156 mm with an accuracy between ± 15 µm and ± 30 µm. Because the desired accuracy of ±5 µm could not be achieved, we consider this milestone as just partially fulfilled.

Milestone 4.1 → complete

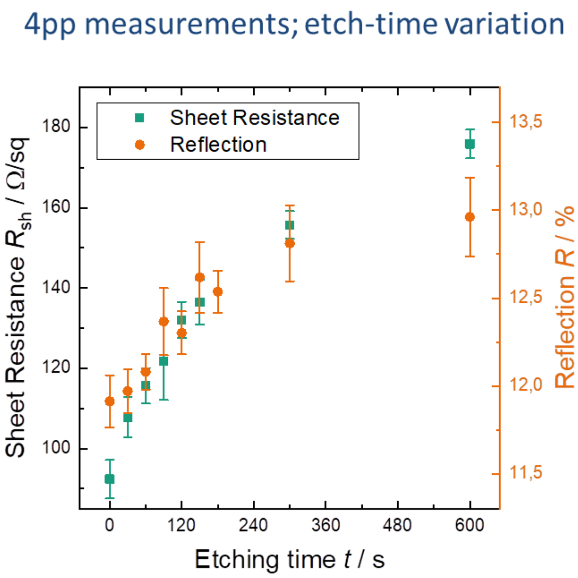
Inkjet printing in the scope of mask&etch processing optimized. Printed features based on printing of hotmelt inks feature a width of below 45 µm on textured surfaces.

With the final ink formula U11912 we are able to print line structures (A) below 45 µm on textured surfaces and maintain this narrow line width until the ink removal (C), thus, also after the etch-back process using a $HF\text{-}HNO_3$ based etch-back solution (B).

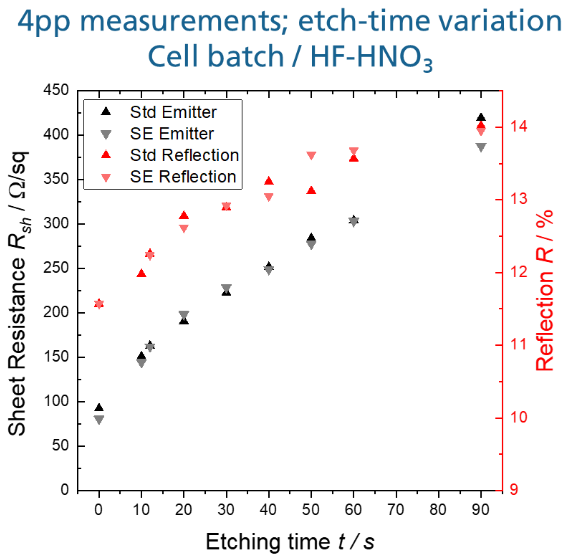


Milestone 4.2 → complete

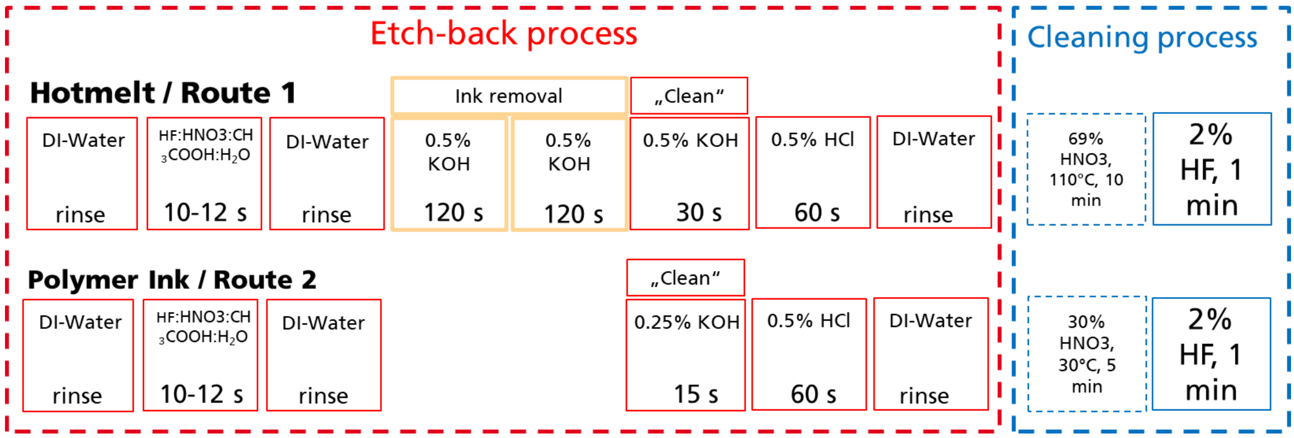
Investigations in the scope of mask&etch processing completed. Doping fingers integrated in the wafer feature
a width of below 45 µm. By setting the etching time, the emitter sheet resistance in the etched region can be precisely adjusted in the range of 60 to 150 Ohm/sq.



The etch-back variation using a HF-persulfate based solution demonstrates that we are able to tune the desired sheet resistance value from 95 ohm/sq (0s) up to 160 ohm /sq (300s) while maintaining the reflection values below 13%. For integration of this process into a PERC cell process flow, etch-back times between 120 to 180 s were selected in order to achieve sheet resistances of 120 to 135 ohm/sq. As reported under WP4, we discovered after a detailed analysis of the etch-back process, a negative interaction of ink and etch-back solution.
Thus, an $HF\text{-}HNO_3$ based solution was investigated as alternative. Evaluations on full-size wafers will were done as well.

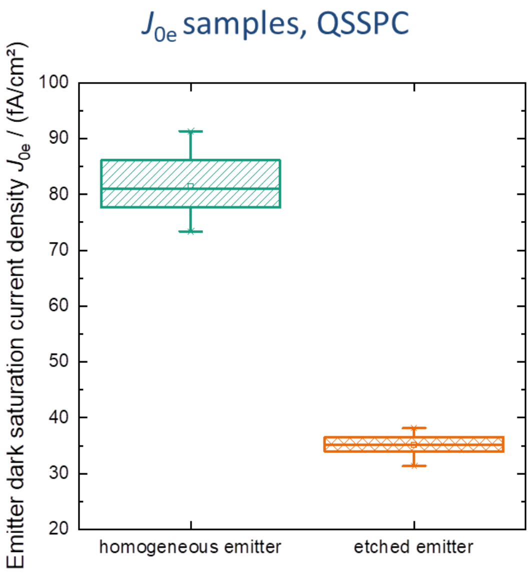


Thus, an HF-HNO3 based solution was investigated as alternative and was implemented into the final cell batch using two different emitter profiles. A further reduction in etch-time of 10-12 s for both emitter types resulting in a sheet resistance in the range of 150 ohm/sq while maintaining low reflection values of 12 to 12.5 % could be obtained. The reduction in process time enables a higher industrial feasibility, while a process time of less than 1 minute was assumed to be adequate. Below is a sketch of the full process sequence for etch-back processing along with cleaning processes prior to passivating, while both process routes differing in inks selection are shown.

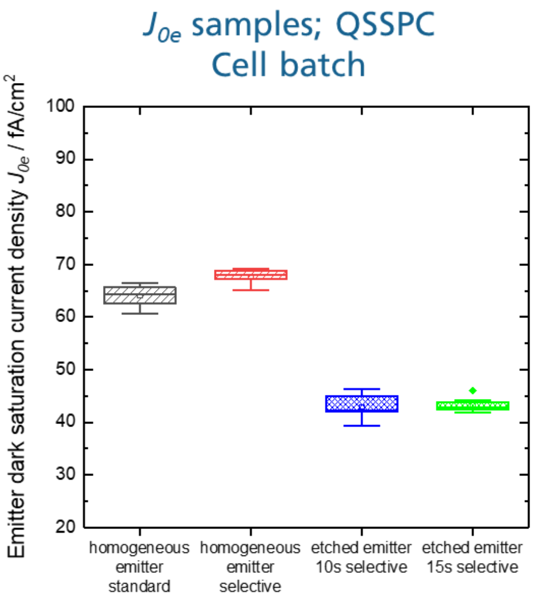


Milestone 5.1 → Complete

The passivation of the selective emitter based on mask&etch processing enables an effective front saturation current density of below 60 fA/cm² and – according to simulations – PERC cells’ conversion efficiencies exceeding 22 %.



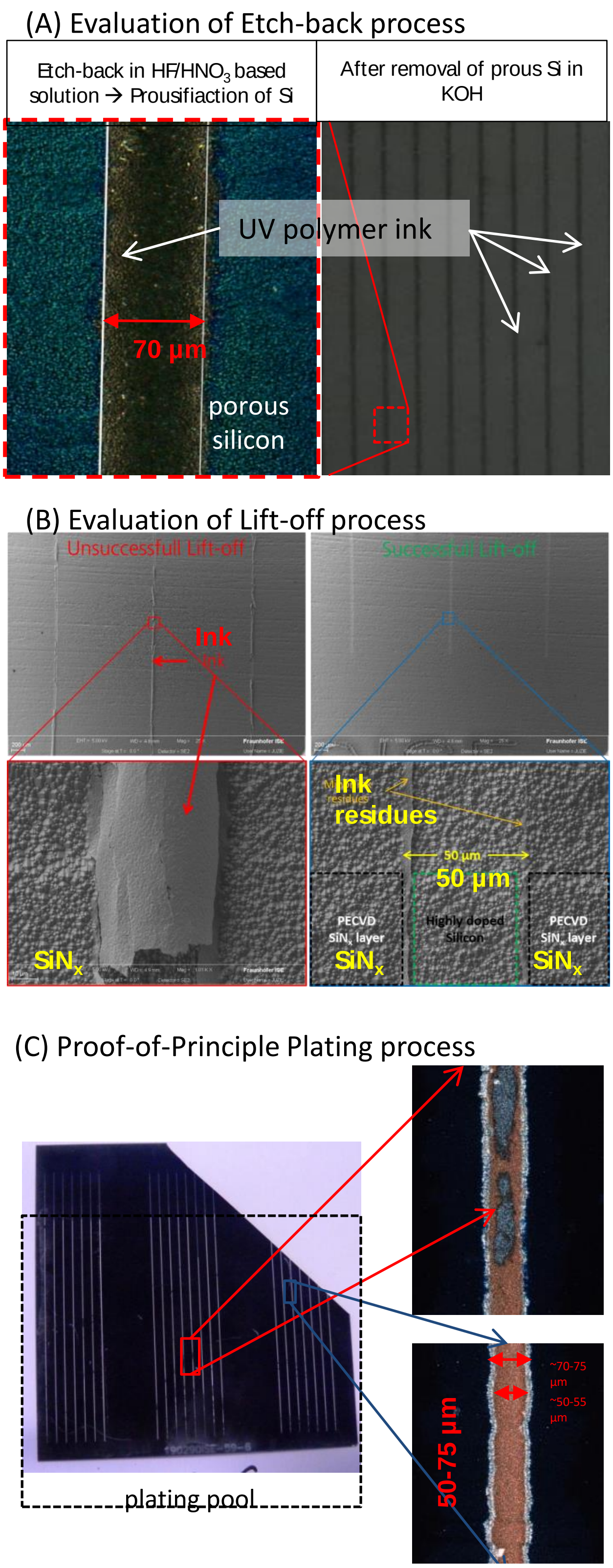
In the course of the cell batch 190102ISE, symmetrical life time samples were produced in order to determine the surface recombination after passivation of the highly doped selective emitter area as well as the etched-back and lightly doped intermediate finger area. Using QSSPC (quasi-steady-state photo conductance) measurements, the emitter saturation current density can be determined, which is a measure of the quality of the passivation. From the results in the graph on the left-hand side, the total emitter saturation current density can be determined. With a selective emitter width of 100 µm and a number of fingers of 110, the area fraction of the selective emitter is approx. 7%. The total emitter saturation current density is therefore 39.45 fA /cm².



As those results are obtained by an HF-Persulfate etch-back solution, evaluation on wafer sized samples using the HF-HNO_3 based solution was done within the final cell batch 200034ISE. From the results in the graph on the left-hand side, the total emitter saturation current density can be determined. With a selective emitter width of 100 µm and a number of fingers of 120 as used in the cell batch, the area fraction of the selective emitter is approx. 7,65%. The total emitter saturation current density of the selective emitter structure is therefore 44,9 fA /cm² compared to 64,9 fA /cm² of the homogeneous standard emitter without etch-back process.

Milestone 5.2 → complete

Self-aligned selective emitter technology based on mask&etch, lift-off, and plating established that is ready for implementation in PERC solar cells’ process sequence. The technology enables a minimal doping/metal pattern’s feature size of below 45 µm.



Despite three inks show similar results regarding thermal and chemical stability as well as similar lift-off behaviour as UV-Hotmelt ink U12445, we achieved superior results regarding printing resolution (Milestone 2.2: 38-44 µm) and, most crucial, very accurate printing behaviour and long-term jetting stability.

With an optimized UV curing process, the ink shows sufficient stability against the HF-HNO_3 based solution and the subsequent removal of the porous silicon using a low concentrated potassium hydroxide solution (>0,5% KOH) as can be seen on the left-hand side (A).

In the SEM images (B), results of a thermally triggered lift-off process can be seen. The thermally triggered lift-off process relies on two main mechanisms. First, the UV-polymer starts to slowly degrade at temperatures above 230°C, second, the volatile part of the UV-Hotmelt matrix triggers a phase change of the hotmelt content cracking the ink structure. Adeauate process conditions were found to be 600°C/1min. On the left-hand, lower side cracks within the ink structure can be observed but still major parts of the ink are not removed. By applying high air pressure, the ink and silicon nitride on top could be fully removed and a lift-off could successfully be demonstrated over the full wafer area. Only minor residues at the edges could be observed.

A sample with the successful lift-off could finally be plated with a Ni/Cu/Ag layer (C). Despite the samples didn’t allow a proper contact on the back-side, we were able to plate into the opened areas. However, we still observe minor interruptions and the improvement of that might be task for upcoming research projects.

In conclusion, we were able to demonstrate the ink-based SiN_x lift-off process with self-aligned plating, hence, the key-enabler for innovative processing of PERC cells with selective emitter. Further optimization of the process steps was done and implemented into the final cell batch 200034ISE and a successful upscaling of processes to an industrial wafer size with industrially relevant equipment was demonstrated as shown in the pictures below. Despite achieving homogeneous plating results and a low contact resistance, as can be seen in the homogeneous response of the electroluminescence image, two principle obstacles remain and must be improved in future work.

- Ghost plating behaviour caused by insufficient plating stability of the low temperature PECVD layer through pinholes; This could be solved by investigating alternative deposition techniques like atomic layer deposition;
- Further reduction in line width by utilizing industrial inkjet print-heads with lower droplet volume allowing for a printed line width of ≤ 20 µm;

In general, plated feature sizes of around 50 µm could be achieved. Thus, the “below 45 µm” were not achieved, however, this is just a minor difference with minor influence on cell performance. Consequently, we define the milestone 5.2 as complete.

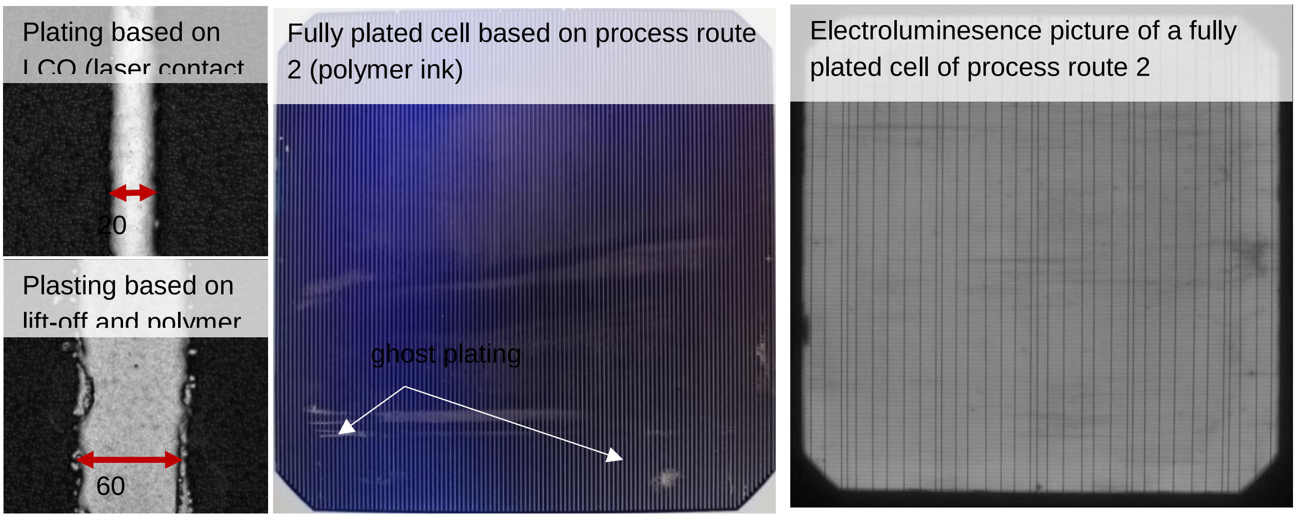


Figure 2 Optical characterization of process route 2 with a self-aligned selective emitter

Milestone 6.1 → Partially complete

Selective emitters have been successfully implemented in the process sequence of PERC solar cells. A vehicle
has been found that enables an average and maximum conversion efficiency of 22.0 % and 22.5 %, respectively.

Within the final cell batch 200034ISE a successful implementation for both process routes could be demonstrated. The following table shows the characteristic solar cell performance parameters from STC (standard test condition). For each process route 1 & 2 the best cell and its reference counterpart with a homogeneous emitter is shown.

Group	η [%]	V_{OC} [mV]	J_{SC} [mA/cm²]	FF [%]
1 Ref. HE | SP30	21.51	665.1	40.1	80.7
2 SE100 | SP30	21.68	670.9	40.0	80.8
3 Ref. HE | PL22	21.53	663.6	40.2	80.8
4 SE55 | PL60	19.89	642.0	38.7	80.1

Process Route 1 (Hotmelt ink)
Process Route 2 (Polymer ink)
HE = homogeneous emitter
SE = selective emitter
SP = screen-printing metallization
PL = plating metallization

For process route 1, a maximum efficiency of 21.7% and a gain of $\Delta\eta$ = 0.16%$_{abs.}$ in efficiency (group 2) could be demonstrated compared to its homogeneous emitter counterpart (group 1) mainly attributed to the gain in open circuit voltage (V_{OC}). Nevertheless, more iteration would be necessary to carefully fine-tune the single process steps to each other in order to fully exploit its potential.

- Improve alignment accuracy to further increase V_{OC}-potential
- Fine-tuning of the emitter dopant concentration profile towards higher concentration in the metal area and lower concentration in the passivation area
- Further improvement of etch-back process in respect to homogeneity, process simplifications and costs

For process route 2, all single processes, partially developed on small wafer sized samples, were combined and implemented into the full PERC process flow in ISE's pilot-line with industrial-size wafers and industrially relevant equipment. Finally, an efficiency of 19,89% could be demonstrated for this self-aligned, challenging, but innovative process route. Losses in V_{OC} and short circuit current (J_{SC}) mainly originate from the increased metal fraction and ghost plating. In order to catch up the reference group, where plating was done on cells with laser-ablated passivation layers, the following developments are recommended:

- Further reduction of the printed line width from 45-60 µm down to 15-20 µm by switching to different industrial inkjet print-heads with lower droplet volume
- Evaluation of alternative low temperature passivation schemes in order to improve passivation quality and supress ghost plating

As both process routes have been successfully implemented into the PERC process flow, we consider this work packages as partially fulfilled as the final efficiency goals have not been reached. The efficiency potential was limited by the quality of the industrial precursors used. As this material was used for the evaluation of all single process steps, it was used for minimizing the risk of failure during solar cell processing. It was intended to have a second cell batch on a material with an even higher quality and improved processes. However, due to severe delay caused by the pandemic situation in 2020, only one major cell batch could be processed.

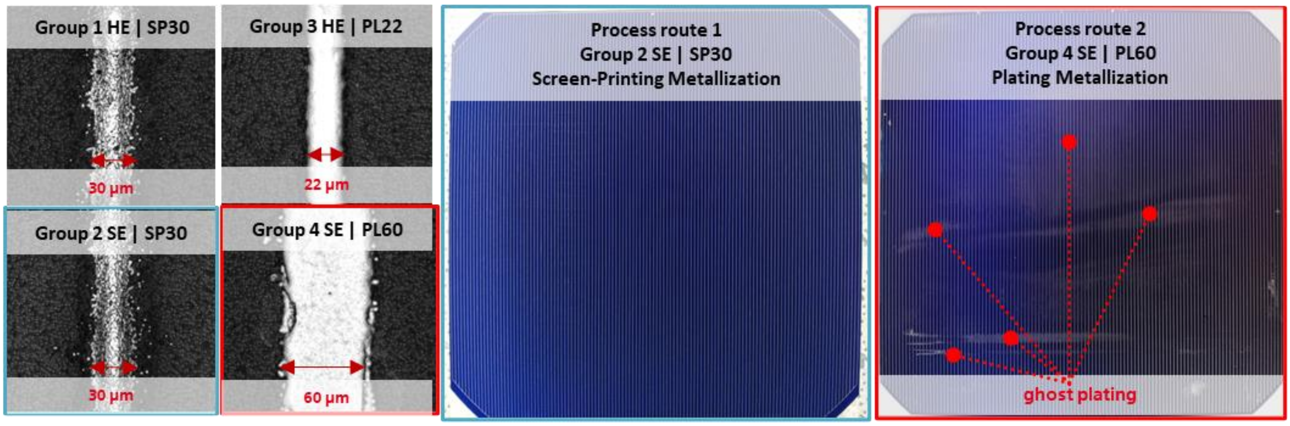


Figure 3 Camera image and corresponding microscopic pictures of the metallization pattern of a fully processed PERC cell with selective emitter for both process routes 1 & 2

Milestone 6.2 → Not complete

The high-volume production of solar cells based on the designated vehicle has been completed. The average conversion efficiency of at least 100 cells is 22.0 % and, consequently, matches the maximum efficiency of the small-volume production.

Due to time constrains caused by the pandemic situation throughout 2020 the timeline of the first experiment planned for 2020 (200034ISE) was severely delayed and an additional iteration to further improve and optimize the process sequence for both process routes within a high volume cell batch (>100 wafer) had to be skipped. Therefore, WP6.2 was not completed. Thus, also the milestone M6.2 and all deliverables connected to it (D6.1 and D6.2). In addition, more iteration would be necessary to fully exploit the potential in order to reach the efficiency range of 22.0 to 22.5% desired.
However, with the project we could demonstrate the technical feasibility of the desired PEarl approaches with conversion efficiency up to 21.7 and potential efficiency gains of up to 0.2 $\%_{abs}$ compared to those which are state of the art. All partners of the consortium would like to further elaborate on that in order to make the next steps towards higher technology readiness levels and commercialization.

Cost Calculations

The main decision criteria for commercialization are the costs expressed by parameters like the total cost of ownership (€/W) and the levelized cost of energy (€/kWh). In the following, sensitivity analysis based on a PEarl model – implemented in sCost – and industrial data on process-related resources were carried out in order to evaluate the desired process routes from a commercial perspective.

The Total Cost of Ownership analysis of the production regarding capital expenditure (Capex) and operational expenditure (Opex) like wafers, consumables and lab costs and many more aim to represent a production site in Central Asia with an annual output of ~1.000 MWp/a, a typical medium fab-size. The following graph shows the so-called Cost of Goods Sold (COGS) for the desired PEarl process. Al single process steps are separately analysed regarding their cost structure.

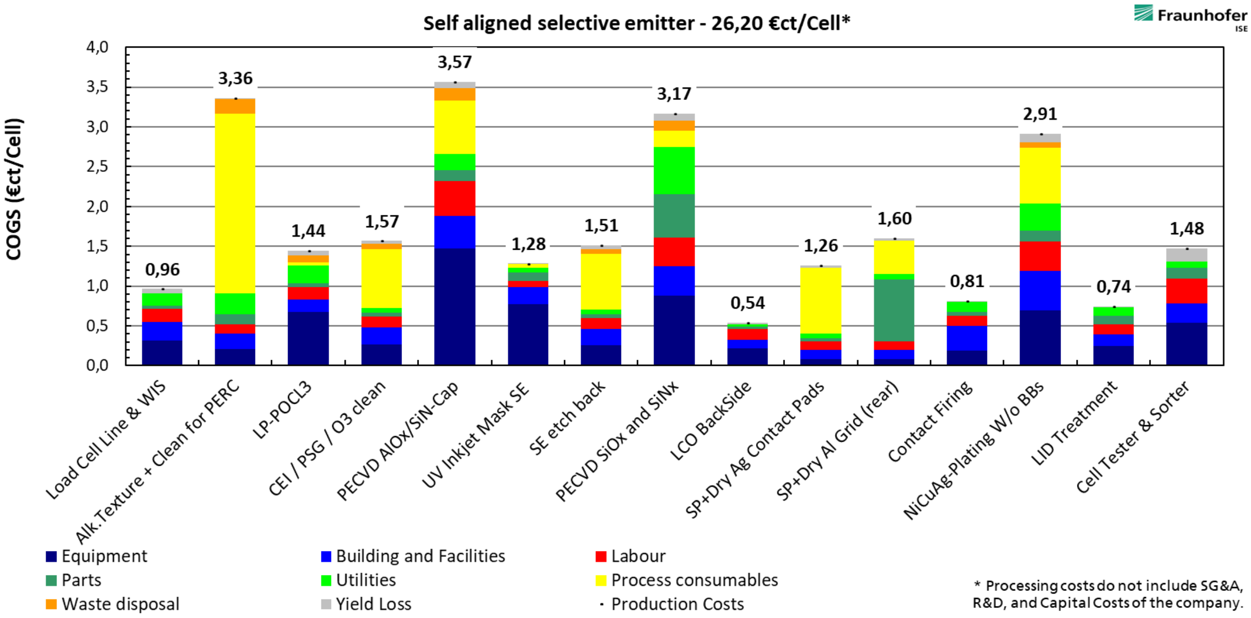


Figure 4 Production Cost (Cost of Goods Sold, COGS) diagram of the self-aligned emitter process flow (pPERC_Sal SE = Selective Emitter self-aligned – Process route 2 optimized)

As can be seen, the COGS of the complete cell process are 26.20€ct/cell, where there is a high potential to decrease the total costs by optimizing alkaline texturing and cleaning, PECVD-deposition, and also the plating. The PEarl processes like inkjet of UV/hotmelt inks for selective etching and lift-off for silicon and silicon nitride patterning, respectively, as a method to integrate selective emitters to PERC are not significant.

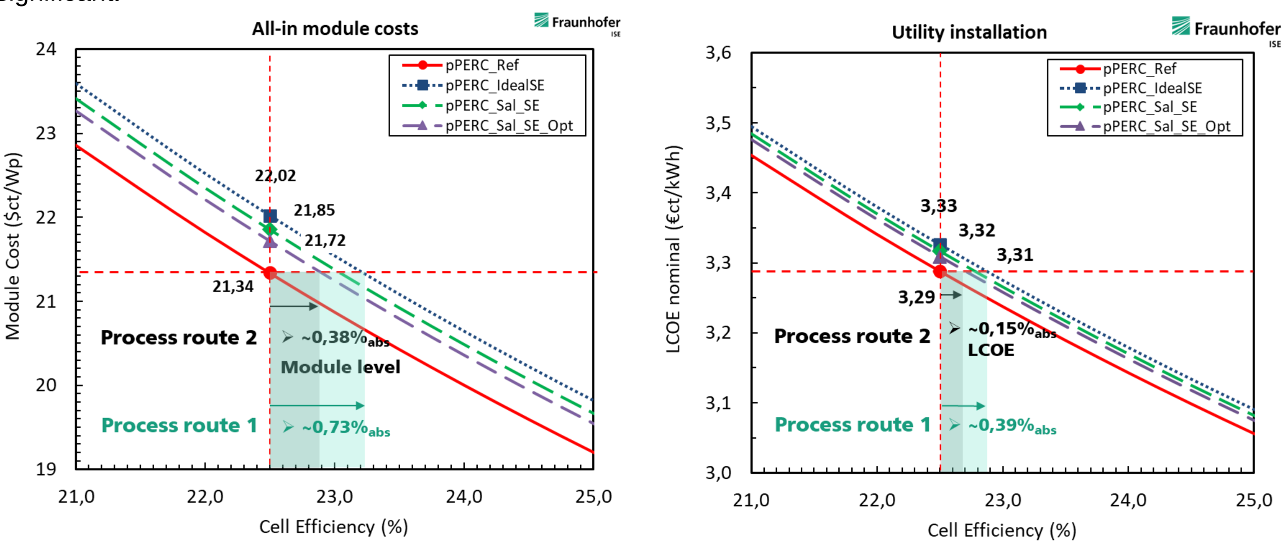


Figure 5 Sensitive analysis of PEarl routes

pPERC_Ref = Homogeneous emitter - Reference process (screen printing metallization)
pPERC_IdealSE = Selective Emitter - Process route 1 (screen printing metallization)
pPERC_Sal SE = Selective Emitter self-aligned - Process route 2 (plating metallization)
pPERC_Sal SE = Selective Emitter self-aligned – Process route 2 optimized (plating metallization)

The sensitivity analysis depicted in Figure 5 indicates the impact of cell efficiency on the TCO for manufacturing modules and the LCOE of solar systems. Or in other words, how much efficiency gain is required to compensate for additional manufacturing costs compared to PERC. As can be derived from the graphs, the PEarl process requires 0.4% on TCO (module) and even less than 0.2% on LCOE level. Thus, a potential gain in efficiency due to the integration of a selective emitter has a really high potential to pay off, especially on LCOE-level. The consortium is sure that the demonstration of a working PEarl technology with significant efficiency gains of even more than 0.2 % is achievable and, if so, a highly attractive option for technology transfer from lab to fab with high potential for all relevant stake holders.

Exploitation of results

A partner-specific exploitation plan including type, quantity, and timeline is depicted in the following table. The main idea is to initiate a follow-up project in order to increase the already high TRL level of around 5 (technology validated in relevant environment) to even higher values, so that technology transfers into the manufacturing industry become even more realistic. Such a project should include a milestone like the missed 6.2 "The high-volume production of solar cells based on the designated vehicle has been completed. The average conversion efficiency of at least 100 cells is 22.0 % and, consequently, matches the maximum efficiency of the small-volume production." in order to achieve a validation at higher lot size. Also, the demonstration of modules would be important to receive a validation along the complete value chain. After a follow-up project and a positive outcome, press releases as well as stake holder meetings should be performed in order to attract potential investors and to bring the PEarl technology into the manufacturing industry. Fraunhofer ISE would guide the technology transfers and profit from R&D contracts and licensing, where Meyer Burger, RENA and Sun Chemical would profit from sales increases.
Currently, all partners experience a growing interest for PV manufacturing plants in Europe. All partners would be happy to transfer the technology into EU-initiatives in order to strengthen the EU-position in this rapidly growing market with potential economic and ecological effects.

Partner	Type	Quantity	Time
All partners	Follow-up project to improve the technology to higher TRL (> 6; technology demonstrated in relevant environment)	1 funded project of around 1-2 Mio €	2022-2023
Fraunhofer ISE	Publications	2	Until 2023
Fraunhofer ISE	Patents	2	Until 2023
Fraunhofer ISE	Education of professionals	2 professionals / year	-
Fraunhofer ISE	Technology transfer (TT) & Licensing	Production capacity 1 GW	2024
Meyer Burger	Machine purchase orders	5-10 production machines per TT	2024
RENA	Machine purchase orders	5-10 production machines per TT	2024
Sun Chemical	Ink purchase orders	500 kg / year per TT	2024

Results, targets and achievements – technological, economic, environmental and other indicators

Issue / Indicator	**Initial value at start of project**	**Expected value at the end of project**	**Reached value**	**Further information**
TRL progress	**4-5**	**6-7**		
Performance / efficiency	**Cell efficiency** 21.3%	**Cell Efficiency** Median 22% Max 22,5%	**Process route 1: 21.67%** Process route 2: 19.89%	**Initial value* & expected efficiencies based on simulations**** Further fine-tuning and high-quality material is needed to further improve efficiency (see. M6.1) ***Saint-Cast et al., pss-a 2017** ****Saint-Cast et al., EU PVSEC 2016**
Effective dark saturation current density of the front side	**Homogenous emitter** **100 fA/cm²**	**Selective emitter** **60 fA/cm²**	**Results from Milestone 5.1:** **>40 fA/ cm²** Cell batch ~45 fA/ cm2	
Alignment accuracy Inkjet to screen printing	**With only minor adaption of process sequence** +/-100 µm	**With development of sophisticated algorithm and alignment procedure** **+/-5 µm**	**Coordinate measurement system +/-15 µm** AOI-System +/-25 µm Cell batch +/- 35 µm	**Final cell batch used the AOI system. Due to the limitation of the image resolution (2540 dpi, pixel size 10 µm) and improper calibration of the AOI system the accuracy is slightly inferior to the pre-test on single cell devices**

Financial Issues

Financial key figures **in EUR** – overall budget at the start of the project

Organisation (Full name of organisation)	Country	Total project costs	Public funding	Funding agency short name
Fraunhofer Institut für Solare Energiesysteme	Germany	€518.980,00	€415.132,00	PTJ
SUN Chemical	U.K.	£330.432,00 €369.729,00	£165.217,00 €184.865,00	TSB
Meyer Burger (Netherlands) B.V.	Netherlands	€140.000,00	€70.000,00	RVO
RENA Technologies GmbH (Observer)	Germany	n.a.	n.a.	n.a.
	Total	1028.709,00	669.997,00	

Dissemination and Communication Activities

In 2019, a talk was given at SNEC conference 2019 in Shanghai:
R. Keding et al., Precise Selective Doping and Metallization for Next-Generation PERC Technology, SNEC 13th, Shanghai (CN), 2019

In 2020 two papers have been submitted at the EUPVSEC conference 2020 in Lisbon:
R. Efinger et al., SELF-ALIGNED SELECTIVE EMITTER FOR PERC BASED ON INKJETABLE UV-POLYMER, in 37th EUPVSEC, Lisbon, Portugal, 2020, 388 - 393

B. Kafle et al., Technological Viability and Proof-of-Concept of Applying Low-Temperature PECVD SiNx for Inkjet-Masked Selective Emitters, in 37th EUPVSEC, Lisbon, Portugal, 2020, 497 - 503

Dissemination activities in numbers

Type of dissemination activities achieved	Year 1	Year 2	Year 3	Total
Peer reviewed articles, books, book chapters etc. published with or submitted to academic publishers	n.a.	n.a.	n.a.	0
Non-peer reviewed publications (reports, briefs, books, articles targeting policy-makers, industry or other end users)	n.a.	n.a.	2	2
Citations to publications generated in the project	n.a.	n.a.	n.a.	0
Media coverage (opinion pieces or interviews/appearances in all types of mass media)	n.a.	n.a.	n.a.	0
Events targeting end users organised by the project (such as conferences, side events or workshops)	n.a.	n.a	n.a	0
Presentations targeting end users given by project participants (including participation in panel debates)	n.a.	1	n.a	1
In how much conferences / events did your project participate (not organised by project itself)?	n.a.	1	1	2
Patent/license applications	n.a.	n.a.	n.a.	0
PhD thesis	n.a.	n.a.	n.a.	0

Master thesis	n.a.	1	1	2
Project internal meetings	16	15	10	41

List of peer reviewed articles, books, book chapters etc. published with or submitted to academic publishers

Type (article, report, book, compendium, journal)	Author(s) *Name(s)*	Title	Published in (Name of publication medium)	Page no.	ISSN/ISBN	Issued/ volume/ year
Choose type	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

List of non-peer reviewed publications (reports, briefs, books, articles targeting policy-makers, industry or other end users)

Type (report, brief, book, article etc.)	Author(s)	Year / publication	Title
Choose type	Name of author	Year of publication	Title of publication
n.a.	n.a.	n.a.	n.a.

List of other dissemination activities (media coverage, events organized by project, presentations and panel debates, participation in third-party events)

Type (media coverage, events organized by project, presentations and panel debates, participation in third-party events)	Description	Year
Choose type	Description of activities	Year in which activity was conducted
n.a.	n.a.	n.a.

List of patents

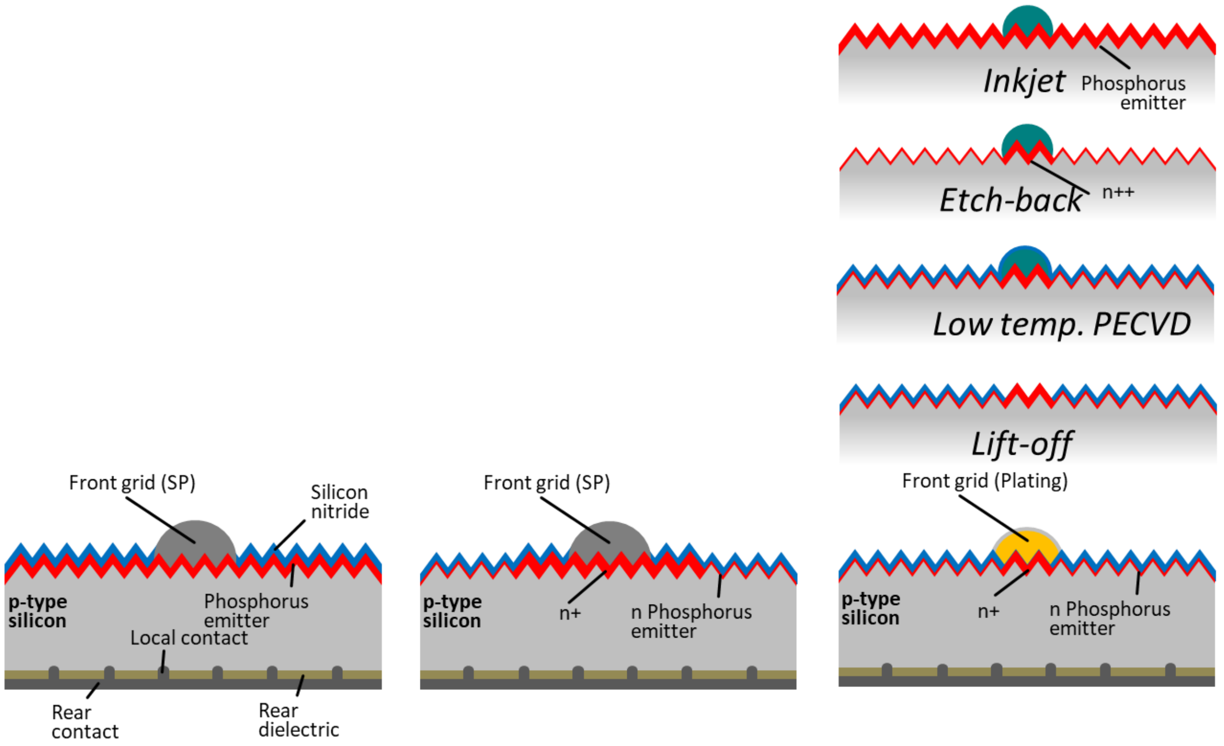
Patent Application Number / License	**Title of the patent application / license**	**Name of the applicant**	**Name of the inventor**
n.a.	n.a.	n.a.	n.a.

Contractual Information

Organisation Full name of organisation	Funding Agency	Contract N° and Title	Duration
Fraunhofer Institut für Solare Energiesysteme, ISE	Project Management Jülich (PtJ)	020ESOLARERANET5-25	01.01.2018 – 30.09.2020
SUN Chemical	Technology Strategy Board (TSB)/ Innovate UK	File Ref.: 620138	01.01.2018 – 30.09.2020
Meyer Burger (Netherlands) B.V.	Rijksdienst voor Ondernemend Nederland (RVO)	TESOL17005	01.01.2018 – 30.09.2020
RENA GmbH	not funded		01.01.2018 – 30.09.2020

Appendix – Project Pearl Process Sequence

<table>
<tr><th>PV-TEC p-Typ Cz-Si Wafer PERC baseline process</th><th>State of the art selective emitter (mask&etch/ Hotmelt)</th><th>Self-aligned selective emitter (UV-hotmelt)</th></tr>
<tr><td>Saw damage etch + texture | alkaline texturing</td><td>Saw damage etch + texture | alkaline texturing</td><td>Saw damage etch + texture | alkaline texturing</td></tr>
<tr><td>Rear side polishing | wet-chemical etching</td><td>Rear side polishing | wet-chemical etching</td><td>Rear side polishing | wet-chemical etching</td></tr>
<tr><td>$POCl_3$ diffusion | thermal processing</td><td>$POCl_3$ diffusion | thermal processing</td><td>$POCl_3$ diffusion | thermal processing</td></tr>
<tr><td>Rear emitter removal | wet-chemical etching</td><td>Rear emitter removal | wet-chemical etching</td><td>Rear emitter removal | wet-chemical etching</td></tr>
<tr><td>Surface cleaning | wet-chemical cleaning</td><td>Surface cleaning | wet-chemical cleaning</td><td>Surface cleaning | wet-chemical cleaning</td></tr>
<tr><td>Rear passivation | AlO_x + PECVD SiN_x</td><td>Rear passivation | AlO_x + PECVD SiN_x</td><td>Rear passivation | AlO_x + PECVD SiN_x</td></tr>
<tr><td></td><td>Selective emitter mask | inkjet printing</td><td>Selective emitter mask | inkjet printing</td></tr>
<tr><td></td><td>Selective emitter etch-back | wet-chemcial etching</td><td>Selective emitter etch-back | wet-chemcial etching</td></tr>
<tr><td></td><td>Ink removal | wet-chemical cleaning</td><td></td></tr>
<tr><td>Anti reflection coating | PECVD SiN_x</td><td>Anti reflection coating | PECVD SiN_x</td><td>Anti reflection coating | PECVD SiN_x</td></tr>
<tr><td>Local contct opeing rear LCO | laser ablation</td><td>Local contct opeing rear LCO | laser ablation</td><td>Lift-off/Ink removal | thermal processing</td></tr>
<tr><td></td><td></td><td>Local contact opening rear LCO | laser ablation</td></tr>
<tr><td>Rear metallization | screen printing</td><td>Rear metallization | screen printing</td><td>Rear metallization | screen printing</td></tr>
<tr><td>Front metallization | screen printing</td><td>Front metallization | screen printing</td><td></td></tr>
<tr><td>Contact firing | inline furnace</td><td>Contact firing | inline furnace</td><td>Contact firing | inline furnace</td></tr>
<tr><td></td><td></td><td>Front metallization | plating</td></tr>
</table>



PERC Process sequence with homogeneous emitter (left) compare to selective emitter process route 1 (centre) and self-aligned process route 2 (right)