ALLSUN

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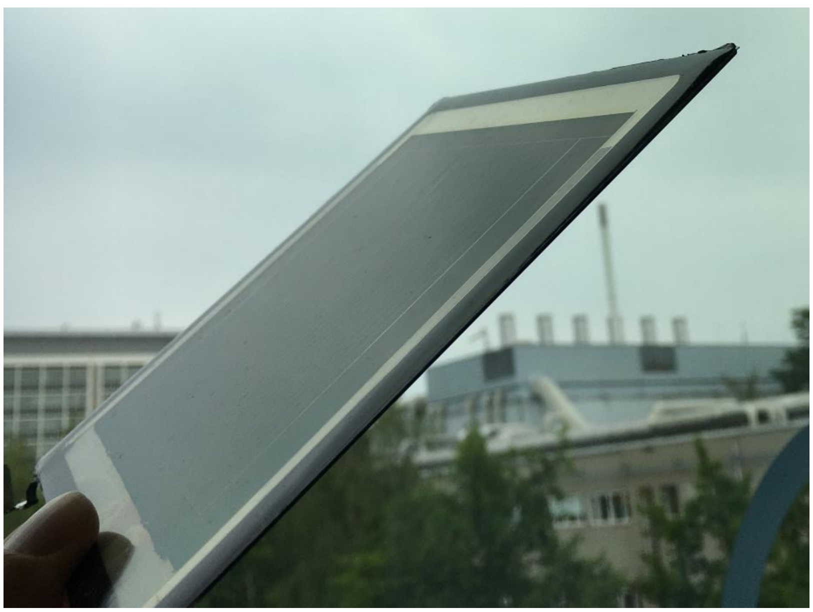

Referentienummer: TEUE117074
Projecttitel: ALLSUN

Wet coated and Atomic Layer deposited functional Layers for Solar modules processed Under Normal atmospheric pressure

Uitvoerder: TNO, Smit Thermal Solutions

Dit project is uitgevoerd met subsidie van het Ministerie van Economische Zaken en Klimaat, subsidieregeling Top Sector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

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1.1 Project number

TEUE117074

1.2 Project title

ALLSUN

Wet coated and Atomic Layer deposited functional Layers for Solar modules processed Under Normal atmospheric pressure

1.3 Consortium

Project coordinator:	TNO
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- Partners:
- **Greatcell Solar (GSL)**
  High Tech Campus 21, 5656 AE, Eindhoven, NL.
  GSL is industrial partner of Solliance. Residents of GSL are located at Solliance and contribute to this project.
  GSL Australia went into voluntary administration Dec. 2018.

- **Meyer Burger (Netherlands) B.V. (MBNL)**, *now STS*
  Luchthavenweg 10, 5657 EB Eindhoven, NL.

- **Smit Thermal Solutions (STS)**,
  Luchthavenweg 10, 5657 EB Eindhoven, NL.

- **Solliance** research partners (**SOL**):

  - **ECN / Solar Energy (ECN)**,
    Thin Film PV group, High Tech campus 21, 5656 AE, Eindhoven, NL, *now TNO*.

  - **TNO / Holst Centre (TNO)**,
    High Tech campus 21, 5656 AE, Eindhoven, NL.

1.4 Project period

January 1st, 2018 until March 31st, 2020.

2. Public summary

2.1 Project aim

Perovskite based photovoltaic technology offers process advantages for manufacturing solar modules. The complete process flow can be executed on existing equipment with the exception of two process steps: a) the perovskite film drying/annealing step and, b) the plasma enhanced atomic layer deposition of transport layers. Equipment for these processes is non-existent today. The goal of ALLSUN is to develop these tools and the corresponding processes.

Main objective

The main objective of ALLSUN is to develop process routes and equipment for solution processed perovskite modules on a relevant scale for the PV industry.

Main project activities

Based on the combined knowledge of processes, equipment engineering and cost calculations, the consortium developed equipment to transfer the laboratory scale processes to sheet-to-sheet and at a later stage roll-to-roll.

- Smit Thermal Solutions realized a sheet-to-sheet process tool consisting of a slot die deposition stage and an in-line perovskite drying/annealing station to obtain high quality perovskite films. The modular tool consists of several chambers. In the first chamber, the wet perovskite precursor ink is deposited by a slot die coater. In the subsequent stations, the wet film is cured under well-controlled conditions, resulting in formation of high quality perovskite films. With this tool, Solliance and GSL transfered laboratory scale processes to an industrial sheet-to-sheet level. Developed equipment and processes will be transferable to roll-to-roll scale.

- In parallel, Meyer Burger and Solliance developed plasma enhanced spatial atomic layer deposited (PE sALD) metal-oxides. The sheet-to-sheet plasma source was installed at the start of the project. Solliance and Greatcell Solar developed recipes on laboratory scale and transferred these to the sheet-to-sheet tool to obtain suitable metal oxide films which function as passivation layer / charge transport layer / metal and water migration barrier / TCO layer. Based on ALLSUN results, TNO and STS are well positioned to introduce PE sALD on roll-to-roll scale.

Main Results

1. Realization of a scalable sheet-to-sheet dry & anneal station for perovskite PV module manufacturing. Perovskite process tools have already been made and shipped to first commercial customers.

Figure 1 Pictures of the dry and anneal tool for sheet-to-sheet produced perovskite layers developed and built by Smit Thermal Solutions and located at TNO/Solliance.

2. Realization of very uniform metal-oxide layer deposited by plasma enhanced spatial atomic layer deposition (PE-sALD) with a width of 30 cm. The first plasma enhanced spatial atomic layer process tools were already made and shipped to first commercial customers.

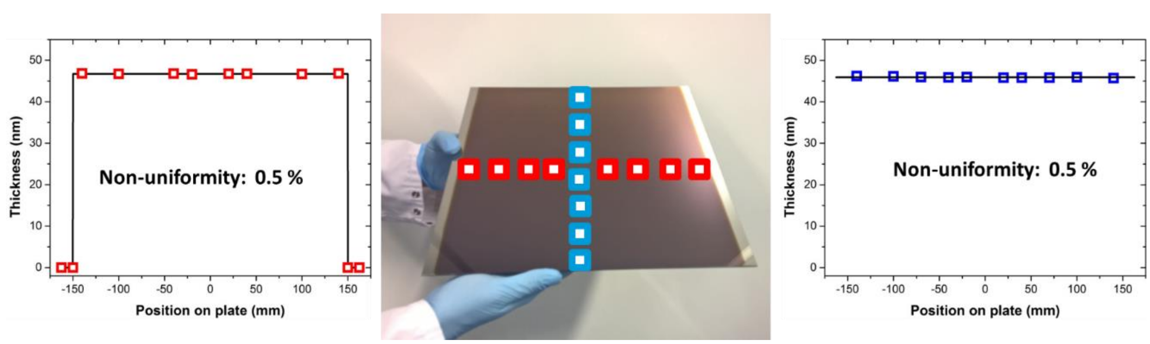

Figure 2 Uniform metal-oxide layer deposited by plasma enhanced spatial atomic layer deposition over an area of 30 x 30 cm^2. The layer thickness variation is well below 1% and less than one nanometer.

3. Industrially scalable processes were deployed to manufacture perovskite modules with state of the art efficiencies. Figure 3 shows an example of a thin film encapsulated bifacial perovskite module.
   Under mono-facial conditions, using a white reflector, the module reaches and efficiency of 16%. Under bifacial conditions, for example bifi200, the quasi efficiency is above 17%. The graph in figure 3 shows the reported efficiency is among the best efficiencies reported for perovskite PV modules.

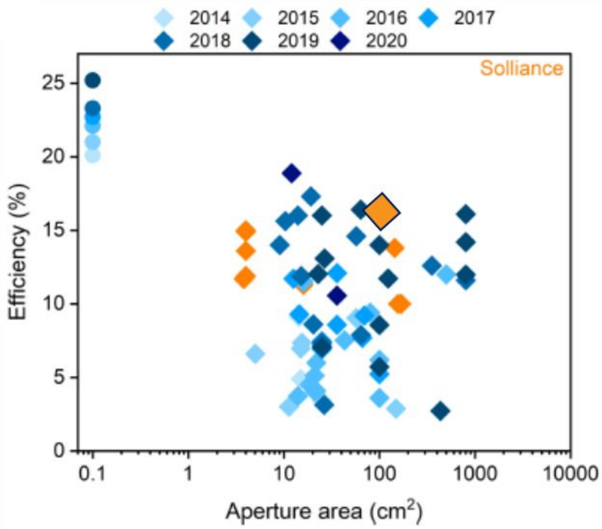

Figure 3 Picture of a thin film encapsulated perovskite bifacial module. The graph shows the power conversion efficiencies of perovskite cells and modules reported in literature. The orange data points represent reported module efficiencies by Solliance.

2.2 Exploitation

The promising results of the ALLSUN project and the continuing commitment of the partners to further support the development of this emerging PV technology and explore the new market opportunities, the consortium members aim to continue the research as it allows new PV applications (multi-junction, translucent PV, flexible efficient tandems, new solutions for BIPV etc.). Perovskite PV also requires high end barrier films. The work on plasma enhanced sALD is very relevant for barrier films.

For Meyer Burger, the project contributed to the development of a fast, ambient process and corresponding tool to deposit thin, pinhole free metal-oxide layers. This technology is relevant for perovskite solar cells as this deposition methods allows to form thin, continuous contact layers which contribute to stable device performance.
The same technology is now also deployed to make oxygen and water barrier films on foils. These foils are used to protect applications like solar cells. The department of Meyer Burger, which developed this technology, partly in ALLSUN, was taken over by Smit Thermal Solutions. It already sold equipment to manufacture ultra-barriers on a roll to roll tool.

For Smit Thermal Solutions, the project led to a tool which allows to convert wet films consisting of a perovskite precursor formulation into a high quality perovskite layer under well controlled conditions. This research tool allows to investigate various curing methods, including convection drying and air quenching and annealing.
Also Smit Thermal Solutions already sold their first equipment for processing perovskite modules during the project. ALLSUN allowed Smit Thermal Solutions to become a front runner in this new PV technology. Perovskite PV may evolve as a successor of the current thin film PV technologies like CIGS and CdTe which are important markets for Smit Thermal Solutions. However it is equally likely, perovskite PV is to complement the PV technology portfolio as perovskite PV is very suitable for tandem applications in combination with existing, well-established PV technologies like cSi and CIGS.
Since Smit Thermal Solutions took over the roll-to-roll spatial ALD technology of Meyer Burger, Smit Thermal Solutions now strengthened its position of supplier to thin film PV manufacturers.

For TNO/Solliance, ALLSUN allowed to scale up perovskite PV technology from laboratory scale to 15 x 15 and 30 x 30 cm^2 scale using industrial processes. This allows TNO/Solliance to prepare relevant demonstrators for companies requesting first devices to evaluate this new technology. The developed technology is relevant for developing single junction perovskite devices as well as for perovskite containing multi-junctions or tandem devices and forms the basis for future projects including MOOI and HER projects to bring this PV technology to the market.

2.3 Project management

The project overview of ALLSUN is schematically represented in Figure 4 and Table 1. The scheme shows 4 technical work packages (WPs). In WP1, novel materials to improve the efficiency and stability of cells and modules have been developed. In WP2, the drying and annealing station has been developed by STS in close collaboration with Greatcell Solar and TNO/Solliance. In WP3, the plasma enhanced spatial atomic layer deposition (PE sALD) technology has been developed by Meyer Burger (later Smit Thermal Solutions), Greatcell Solar and TNO/Solliance. In WP4, the most promising results from WP1 were transferred from laboratory scale to sheet-to-sheet (drying and annealing station) and roll-to-roll scale (PE sALD).
WP5 was important for the companies Meyer Burger and Smit Thermal Solutions as it steered the direction of the project in the direction to result in commercially relevant developments like the drying and annealing station and the PE sALD process of barrier layers. Finally, in WP6, the project management activities were executed, like arranging regular meetings and reporting.

Figure 4 Project overview of ALLSUN.

WP	Description	Cat.	Partners	Result	Status
1	Lab scale processing	IO	TNO, GSL	Process flows available for PSCs prepared on lab scale acting as benchmark for S2S processed devices.	achieved
2	Drying / annealing station	IO	STS, TNO, GSL	S2S D/A tool operational: layer thickness variation ≤ 10 % (rel.) over 30 x 30 cm^2.	Achieved on 15 x 15 cm2 (limited by laser)
3	Plasma Enhanced sALD	IO	TNO, MBNL, GSL	S2S PE sALD tool operational: layer thickness variation ≤ 2 % (rel.) over 30 x 30 cm^2 proven for two different metal-oxide layers.	achieved
4	S2S Processing	IO	GSL, TNO	PSCs processed on both the S2S slot die coater with in line D/A station and S2S (PE) sALD tool reaching > 16.5% ± 0.8% reproducibly over 30 x 30 cm^2.	achieved
5	Exploitation	IO	MBNL, STS, GSL, TNO, ECN	Commercial viability of D/A and PE sALD tools for rigid and flexible perovskite PV.	achieved
6	Management	IO	ECN	Project management, CA & Reporting.	achieved

Table 1 Project structure of ALLSUN and planned results & status at end of project