SUCCESS
Sequential, high Uniformity, Cost Competitive Elemental Selenization and Sulphurization for CIGSSe2

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Publishable Summary

Thin-film photovoltaic CIGS technology has seen considerable growth of manufacturing capacity in recent years. The environmental impact, especially the CO_2 footprint of CIGS thin-film panels shows great advantages compared to other solar technologies. CIGS panels show good performance in diffuse light conditions and at high temperatures and are tolerant to partial shading. Additionally, the aesthetic qualities and the possibility of custom colors make CIGS a superior PV technology for the application in building integrated photovoltaics (BIPV), e.g. in solar façades.

During the period between 2016 and 2019, the conversion efficiency of CIGS record cells has been increased from 20.5% to 23.35%, an improvement mainly attributed to the use of controlled Post Deposition Treatment (PDT) of the absorber layer with heavy alkali metals. In this project, the consortium aimed to systematically investigate the impact of sodium and/or heavy alkali doping before, during or after the absorber formation process and to ultimately apply this technology to large-area module production processes with a Cd-free buffer process.

The fabrication process of the CIGS semiconductor layer is the key driver for both, the further increase of efficiency, and the reduction of manufacturing cost of CIGS solar modules. In the framework of SOLAR-ERA.NET, the solar companies Smit Thermal Solutions and AVANCIS started a European collaboration with the leading research institutes Helmholtz-Zentrum Berlin (HZB), CNRS (Institut des Matériaux Jean Rouxel de Nantes) and TNO/Solliance with the project 'Sequential, high Uniformity, Cost Competitive Elemental Selenization and Sulphurization for CIGSSe2', abbreviated as SUCCESS. The aim of SUCCESS is the combination of a further cost-optimized CIGS processing and the high efficiencies reached with heavy alkali post-deposition treatment (PDT).

As an essential step for scaling up, the homogeneity of the selenization process in the Smit Thermal Solutions equipment has been significantly improved by a new showerhead and sample carrier design, pushing down the COV (Coefficient Of Variation) for Selenium to below 4.2%, on 30x30 cm^2.

The non-vacuum Smit Thermal Solutions in-line selenization and sulphurization equipment provides a high degree of freedom in the CIGS semiconductor fabrication enabling further cost reduction at high efficiency levels. Using Smit Thermal Solutions 30x30 cm^2 semi-industrial equipment, notable efficiencies have been achieved by TNO/Solliance and HZB at cell level, with a record 18.41% achieved in this project, externally certified by Fraunhofer ISE Freiburg. This result was achieved by using a combined NaF and RbF PDT process by HZB. Additionally, the low V_{OC} deficits relative to the band gap (lowest ≈375 mV, no PDT) suggest a high quality CIGSSe material prepared with the Smit Thermal Solutions tool. The process conditions for AVANCIS precursors turned out to be notably different, and, despite several modifications were tested, the partners

failed to demonstrate similar high efficiencies in this project.

CNRS-IMN has explored a unique approach of performing PDT processes under a sulphur atmosphere. Among the various processes investigated, inc. Cs, Rb and/or Na addition, the best results were achieved with an In + RbF(S) process raising efficiency for the co-evaporated CIGS of CNRS-IMN from 16.8% (ref w/o PDT) to 19.3% (without anti-reflective coating).

On AVANCIS sequential pilot line absorbers most successful results were obtained by a NaF & RbF PDT process at room temperature followed by an anneal in sulphur atmosphere (HZB) or a In + RbF(S) PDT optionally combined with a thin In2S3 alkali sink (CNRS-IMN), both significantly raising the Voc relatively to the reference non-treated absorber. Nevertheless, compared to AVANCIS pilot line PDT processing, the device efficiencies with the new developed PDT processes were finally not improved.

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Project consortium

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Participating countries and financing:

Country	**Number of organisations involved**	**Project costs in EUR**	**Public funding in EUR**
The Netherlands	2	657 720	383 566
Germany	2	1 066 474	901 808
France	1	250 992	220 824
Total	*5*	*1 975 187*	*1 506 198*

Funding agencies involved and contracts

Funding Agency	Contract N° and Title
RVO	SOL193W32U project SOL18006 «Besluit tot verlening subsidie»
PTJ	03EE1025A und 03EE1025B: Verbesserung der Effizienz und Gleichförmigkeit von sequentiell hergestellten Cu(In,Ga)(S,Se)2 Solarzellen (Kontrollierte Dotierung, Wechselwirkung von Alkalinachbehandlungen)
ANR	ANR-19-SOL2-0003-05