In4CIS
New in-line optical methodologies for advanced assessment of high efficiency CIGS industrial processes

Project duration: from 09.2019 to 12.2022
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Publishable Summary

In4CIS has established and demonstrated at pre-industrial level new advanced optical methodologies for the in-line assessment of advanced processes in Cu(In,Ga)Se2 (CIGS) thin film photovoltaic technologies. In particular, these have been applied to the monitoring of RbF postdeposition treatments (PDTs) employed for the production of very high efficiency CIGS devices. RbF PDT processes have allowed achieving solar cells with reproducible efficiency values > 20% (with a record certified value of 22.6%), in the frame of the Sharc25 H2020 project that was coordinated by ZSW (http://sharc25.eu/). However, the successful transfer of these process concepts from cell (cm2) to module (m2) scale at pre-industrial level requires the detailed assessment of the uniformity of the processed layers, as inhomogeneities are one of the main performance loss mechanisms that decrease photovoltaic efficiency when scaling up CIGS PV technologies to module size. In this way, the optimisation of the PDT processes requires high sensitivity tools and methodologies that allow assessing the uniformity of the processed layers during fabrication, detecting the appearance of inhomogeneities at an early production stage in the process line. In this regard, optical techniques like those developed in In4CIS enable a fast and non-destructive inspection compatible with in-line monitoring.

The optical methodologies developed in In4CIS are based on the combined use of Raman and photoluminescence (PL) spectroscopic techniques, which have been integrated into multi-sensor in-line process monitoring tool (Figure 1) for the advanced non-destructive quantitative assessment of the uniformity of the surface region of the CIGS absorbers. The combination of these techniques in a single sensor together with the development of advanced methodologies for data acquisition and processing has allowed implementing a fully functional inspection system that provides a very high measuring sensitivity to PDT effects on the CIGS material with fast measuring times compatible with its implementation in industrial environments at in-line process monitoring level, which is critical to ensure high throughput/high yield industrial processes as required for competitive CIGS PV production lines. This tool has been installed, tested and validated in real operating conditions at ZSW's CIGS pilot line, where it has been proven to be able to detect with very high precision variations and inhomogeneities in pre-industrial CIGS absorber material (30 x 30 cm2) leading to Voc fluctuations lower than 2% in the final devices in an inspection time below 5 min. This sets the basis for the industrialization of CIGS PV technologies with advanced PDT processes. Additionally, the development of the process

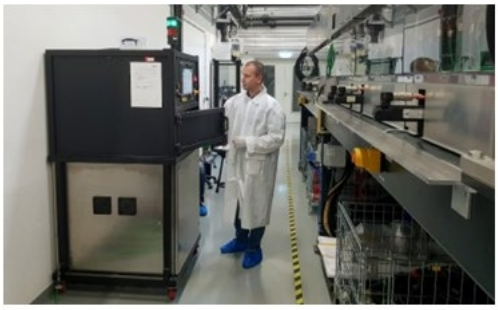

Figure 1. Process monitoring tool installed at ZSW's CIGS pre-industrial pilot line.

monitoring methodologies and tools in In4CIS has required the fundamental characterization of the impact of RbF PDT on CIGS devices. This has led to the generation of deep fundamental scientific and technological knowledge of the CIGS material that will enable the further development of this promising thin film PV technology.

The development of the In4CIS project has been possible thanks to the cooperation of an international consortium formed by five complementary partners: 1) IREC (Spain) an RTO with high expertise in thin film photovoltaics who has acted as project coordinator and has been the main responsible for the advanced fundamental characterization as well as for development of the optical methodologies and sensors of the process monitoring tool, 2) University of Barcelona (Spain) who has contributed in the advanced fundamental characterization of the RbF PDT impact on CIGS devices, 3) LENZ (Spain) a metrology company who has designed and implemented the final process monitoring tool according to industrial standards, 4) ZSW (Germany) an RTO at the forefront of the development the CIGS PV technology who has provided their very high efficiency CIGS PV technology and who has tested and validated the process monitoring tool in their pre-industrial pilot line, and 5) MANZ (Germany) a company with large experience in the implementation of industrial PV production lines who has contributed in the techno-economic assessment of the inspection system.

Project consortium

Coordinator and all contact details:

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Participating countries and financing:

Country	**Number of organisations involved**	**Project costs in EUR**	**Public funding in EUR**
Spain	3	373 133	303 167
Germany	2	383 626	360 525
Total	***5***	***756 759***	***663 692***

Funding agencies involved and contracts

Funding Agency	Contract N° and Title
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CDTI	EXP - 00128144 / SERA-20201007
Projektträger Jülich (PtJ)	• 03EE1020A «Verbundvorhaben: In4CIS – Neue in-line Methodik für fortgeschrittene Bewertung von hocheffizienten industriellen CIGS Prozessen; Teilvorhaben: Probenpräparation und Prototyp-Validierung am ZSW» • 03EE1020B «Verbundvorhaben: In4CIS – Neue in-line Methodik für fortgeschrittene Bewertung von hocheffizienten industriellen CIGS Prozessen; Teilvorhaben: Technische und ökonomische Evaluierung der industriellen Anwendung der entwickelten in-line Methodik für fortgeschrittene Bewertung von hoch-effizienten CIGS Prozessen»