« Exchange of Experiences » - Webinar

Insights, outcomes and results – 28 September 2023

In4CIS

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

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Scientific, technical, commercial challenge(s) addressed

- $Cu(In,Ga)Se_2$ (CIGS) is a thin film PV technology with great potential for high efficiency, low cost and compatible with advanced PV concepts (flexible, integrable, semi-transparent, etc.)
- At laboratory level, CIGS devices require the use of an advanced RbF post-deposition treatment (PDT) that allows achieving solar cells with efficiency values > 20%
- ZSW is scaling up the RbF PDT process to pre-industrial level (30 x 30 cm^2) for demonstrating the feasibility of industrializing the technology
- Inhomogeneities are the main performance loss mechanisms when scaling from lab to module size

Main challenge: Demonstration of high sensitivity tools and methodologies for monitoring ZSW's advanced CIGS production process that allow detecting the appearance of inhomogeneities (≤ 2%) at an early production stages (RbF PDT) in a fast and non-destructive way using optical techniques

Challenge 1: Fundamental understanding of the impact of RbF PDT on the CIGS material

Challenge 2: Development of sensors and methodologies compatible with RbF PDT process monitoring

Challenge 3: Build a functional process monitoring industrial demonstrator tool to implement at ZSW's pilot line

Challenge 4: Validation of the tool in real operation conditions

Challenge 5: Techno-economic assessment of the technology

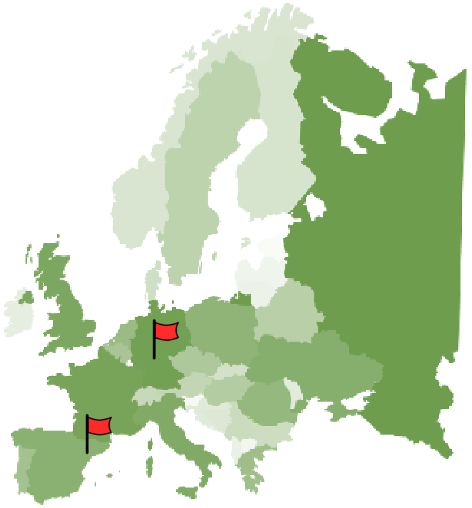
Project consortium

SPAIN

IREC – Shaping Energy for a Sustainable Future: RTO (Coordinator) – Fundamental characterization, development of sensors and methodologies (Challenges 1, 2, 3, 4)

Universitat de Barcelona: UNI – Fundamental characterization (Challenge 1)

Lenz Instruments: SME – Implementation of industrial demonstrator (Challenge 3)



GERMANY

ZSW: RTO – Fabrication scale-up, sample fabrication, process optimization, tool validation (Challenges 1, 4)

manz: Large company – Counseling and techno-economic assessment (Challenge 5)

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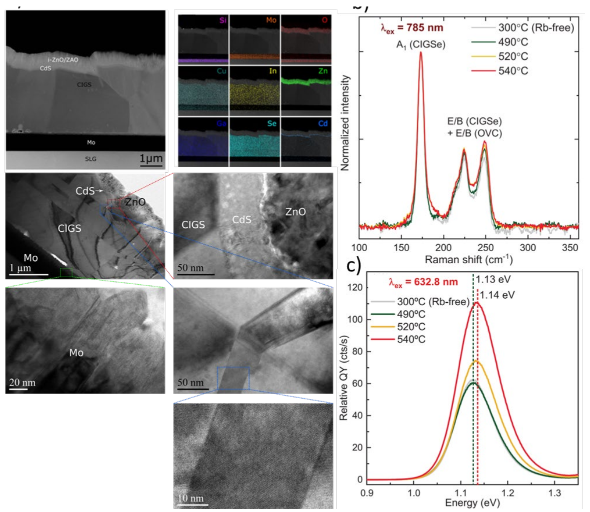
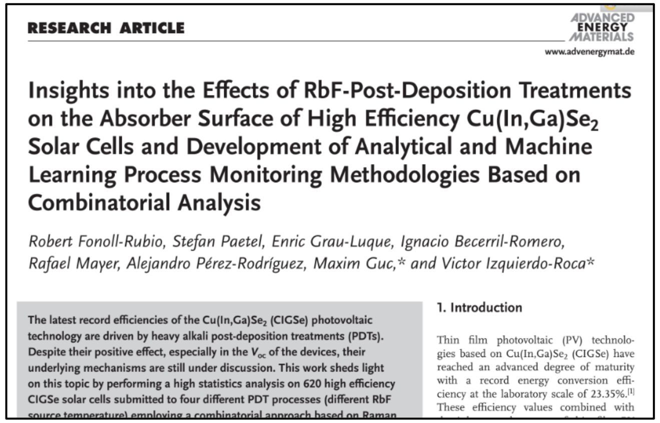
Key outcomes and results

Challenge 1: Fundamental understanding of the impact of RbF PDT on the CIGS material

- New fundamental knowledge about the effects of RbF PDT on the CIGS material through the combination of advanced spectroscopic techniques (Raman and photoluminescence) and electron microscopy (SEM, TEM)
- Publication of article in very high impact factor (29.7) journal Advanced Energy materials





RESEARCH ARTICLE

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Insights into the Effects of RbF-Post-Deposition Treatments on the Absorber Surface of High Efficiency Cu(In,Ga)Se_2 Solar Cells and Development of Analytical and Machine Learning Process Monitoring Methodologies Based on Combinatorial Analysis

Robert Fonoll-Rubio, Stefan Paetel, Enric Grau-Luque, Ignacio Becerril-Romero, Rafael Mayer, Alejandro Pérez-Rodríguez, Maxim Guc, and Victor Izquierdo-Roca**

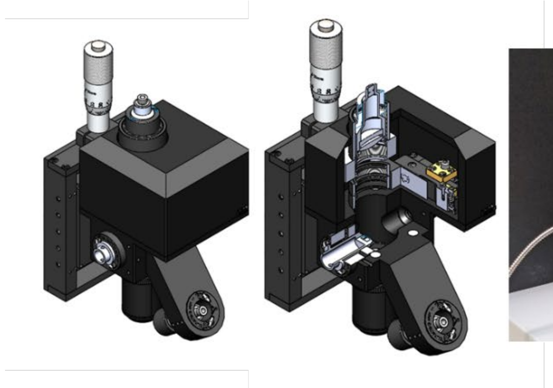
The latest record efficiencies of the Cu(In,Ga)Se_2 (CIGSe) photovoltaic technology are driven by heavy alkali post-deposition treatments (PDTs). Despite their positive effect, especially in the V_{oc} of the devices, their underlying mechanisms are still under discussion. This work sheds light on this topic by performing a high statistics analysis on 620 high efficiency CIGSe solar cells submitted to four different PDT processes (different RbF source temperature) employing a combinatorial approach based on Raman

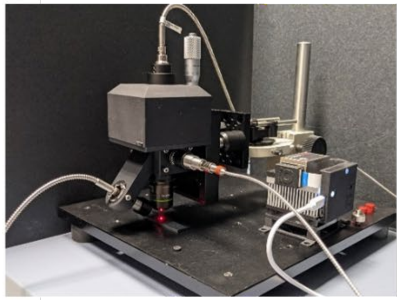
1. Introduction

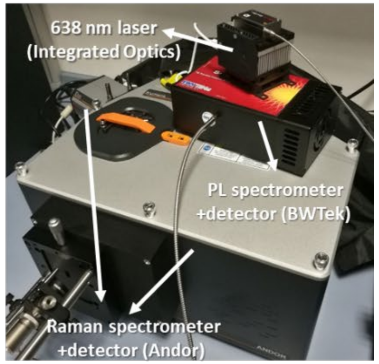
Thin film photovoltaic (PV) technologies based on Cu(In,Ga)Se_2 (CIGSe) have reached an advanced degree of maturity with a record energy conversion efficiency at the laboratory scale of 23.35%.[1] These efficiency values combined with

Challenge 2: Development of sensors and methodologies compatible with RbF PDT process monitoring

- Novel multifunctional Raman + Photoluminescence sensor optimized for the high sensitivity inspection of the CIGS material and compatible with industrial environments



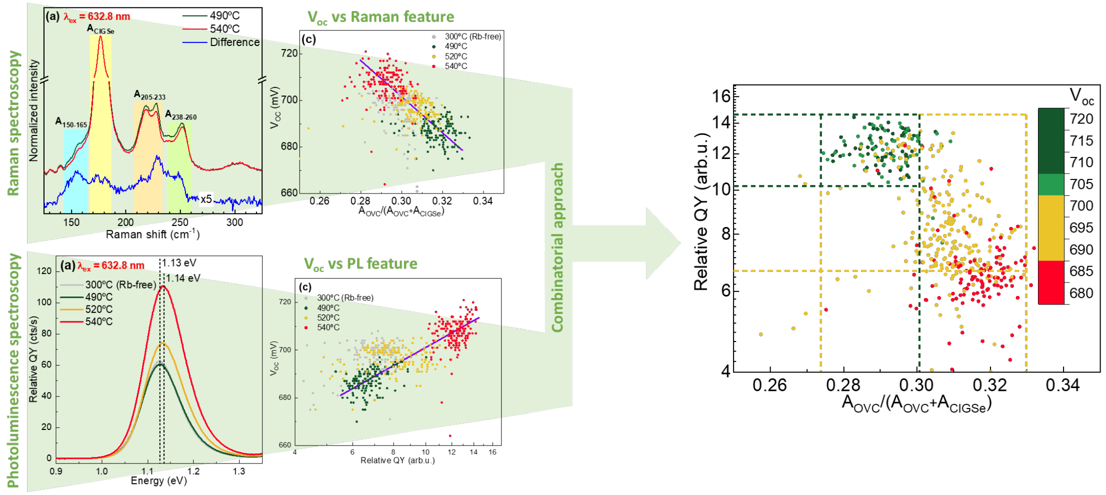




Key outcomes and results

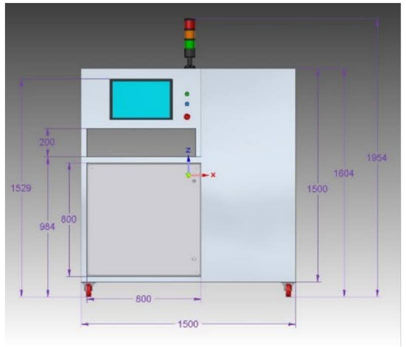
Challenge 2: Development of sensors and methodologies compatible with RbF PDT process monitoring

- Methodology based on Raman + Photoluminescence spectroscopic data that allows detecting deviations (≤ 2%) and predicting the final Voc of the final PV devices at an early production stage (after the RbF PDT process) ➔ compatible with in-line industrial process monitoring



Challenge 3: Build a functional process monitoring industrial demonstrator tool to implement at ZSW's pilot line

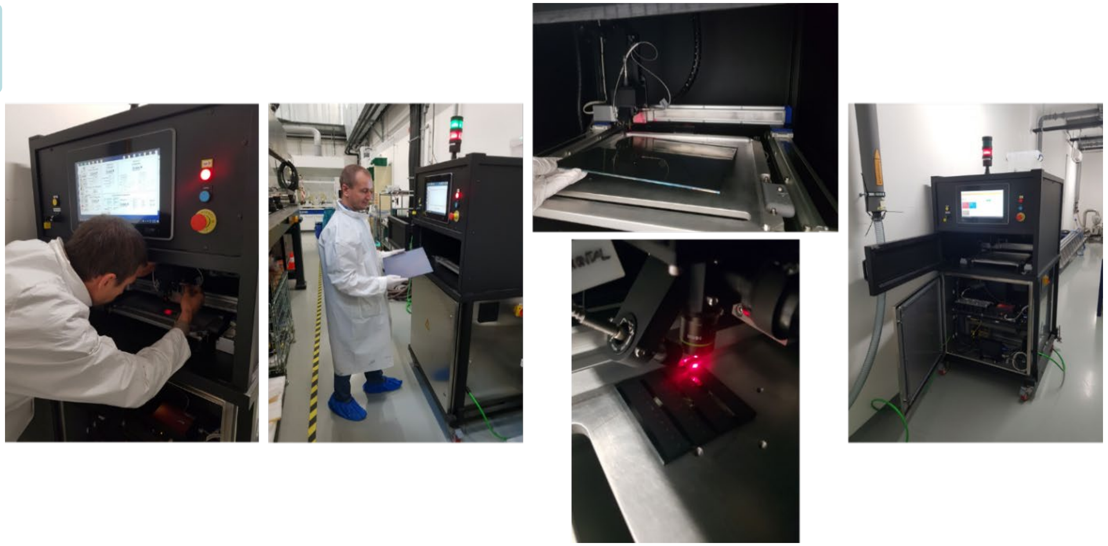
- Design and implementation of process monitoring industrial demonstrator tool compatible with the in-line inspection of ZSW's production in < 300 s/module
- Development of control and data analysis software with graphical user interface

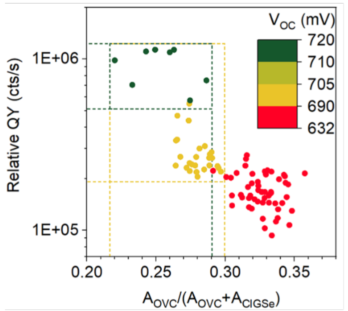


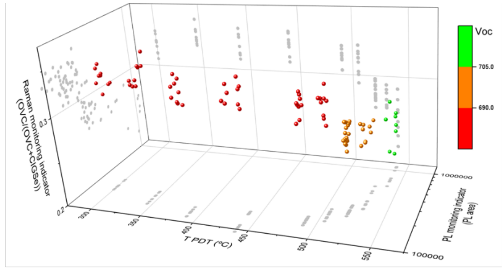
Key outcomes and results

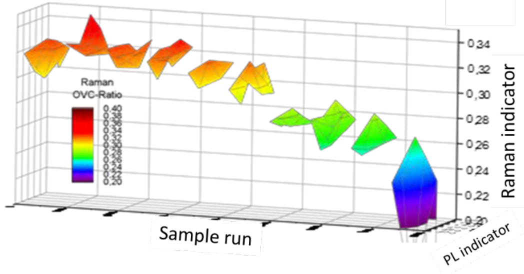
Challenge 4: Validation of the tool in real operation conditions

- Installation and set-up of the fully functional demonstrator at ZSW's CIGS pilot line.
- Validation of the tool under real operation conditions
- The performance of tool complied with the project objectives: map a 30x30 cm^2 module in ≤ 300 s and detect deviations (inhomogeneities) ≤ 2%







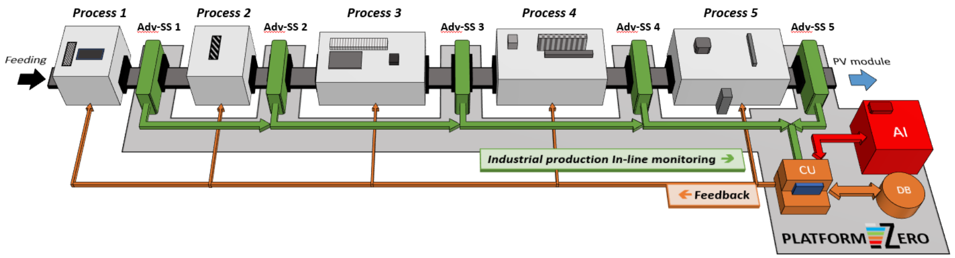


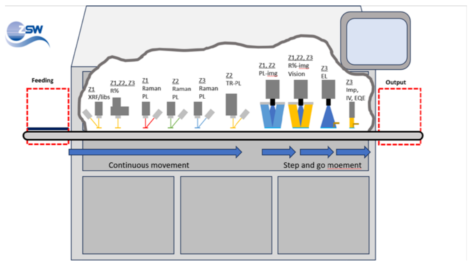
Challenge 5: Techno-economic assessment of the tool

- Engagement of the CIGS industrial PV producer AVANCIS through proof-of-concept demonstration of the process monitoring tool with their PV technology
- The In4CIS technology (RbF PDT + process monitoring) was estimated to provide a production cost reduction of ~6% (from 40.0 to 37.6 €/Wp) in large scale CIGS production lines with negligible extra cost

Benefits and experiences gained in transnational set-up

- Demonstration of an advanced CIGS PV technology at pre-industrial level (TRL 7), including production and process monitoring, relevant for the future of EU's PV industry ➔ only possible with transnational collaboration between research and industrial institutions
- Creation of solid research and industrial transfer collaboration network at national and transnational level among top EU research centers and companies
- Opening of new collaboration opportunities in the Horizon Europe funding scheme:
  - **Platform-ZERO** (GA 101058459, Jan 2023 – Dec 2026) [Project budget € 10.190.043,75] ➔ IREC, ZSW and LENZ collaborate in a new project to expand the process monitoring technology developed in In4CIS to other advanced PV technologies and production processes using AI. https://www.platform-zero-project.eu/





  - **Hi-BITS** (GA 101122203, Oct 2023 – Sept 2026) [Project budget € 4.962.618,54] ➔ IREC and ZSW collaborate in a new project to improve the CIGS PV technology towards new efficiency limits together with the development of process monitoring methodologies for its future industrialization. https://cordis.europa.eu/project/id/101122203

Critical factors & lessons learned for future successful transnational R&I projects

- Fluid communication between partners is fundamental for the coordination between the different partners ➔ organization of periodic consortium meetings, short follow-up meetings and bilateral meetings
- Internal reporting of results is critical for tracking the technical progress of the project, prepare official reporting at ERA.net and national level and plan future actions
- Timing desynchronization of the different partners may occur due to different starting dates of national subprojects ➔ the impact can be minimized by slight replanning of the timing of the project activities
- The involvement and strong open collaboration of companies and research transfer entities is very advisable to ensure that the project results can have a real impact in society and can contribute to the industrial development of PV in Europe

Thank you very much for your attention

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