SUCCESS

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

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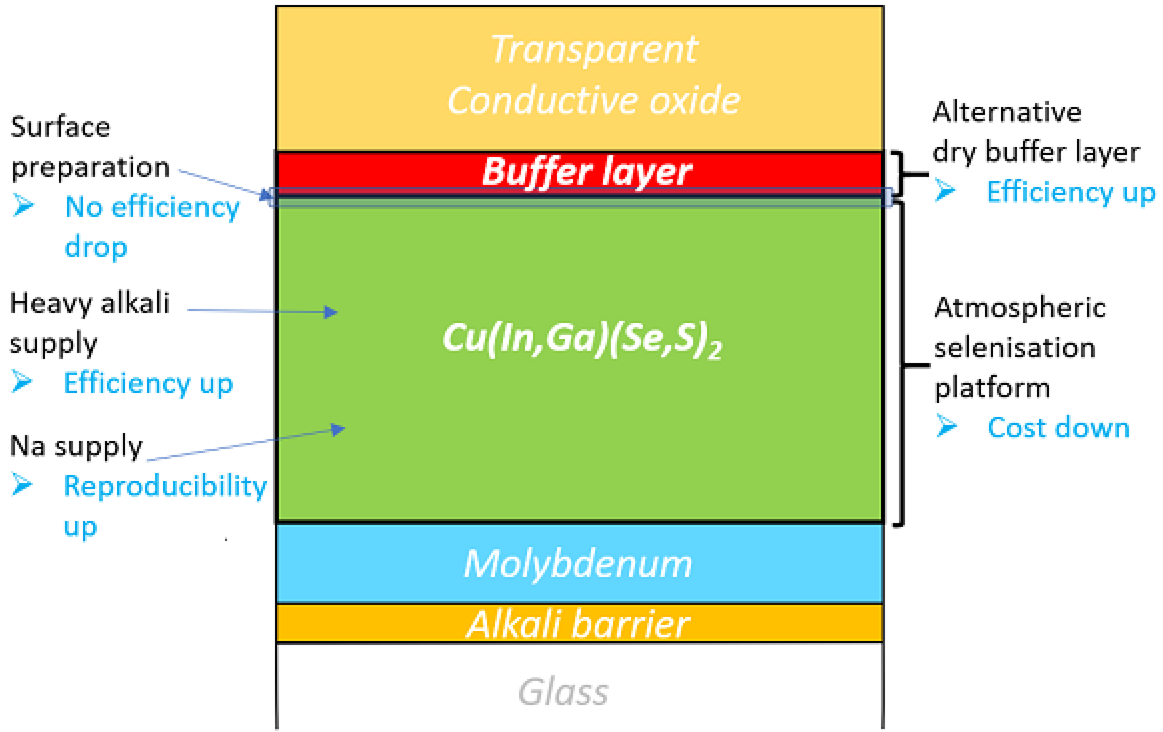
Context

- between 2016 and 2019 CIGS record efficiency cells 20.5% > 23.35%
- mainly attributed to the use of controlled Post Deposition Treatment (PDT) of the absorber layer with heavy alkali metals

Aim of the project

- Improve efficiency of industrially predominant sequential CIGSSe thin-film solar cells through an effective and controlled supply of Na and heavy alkali doping (fabrication-alkali-buffer)
- Qualify the costdown Smit Thermal Solutions (NL) atmospheric inline process for highly efficient CIGSSe devices



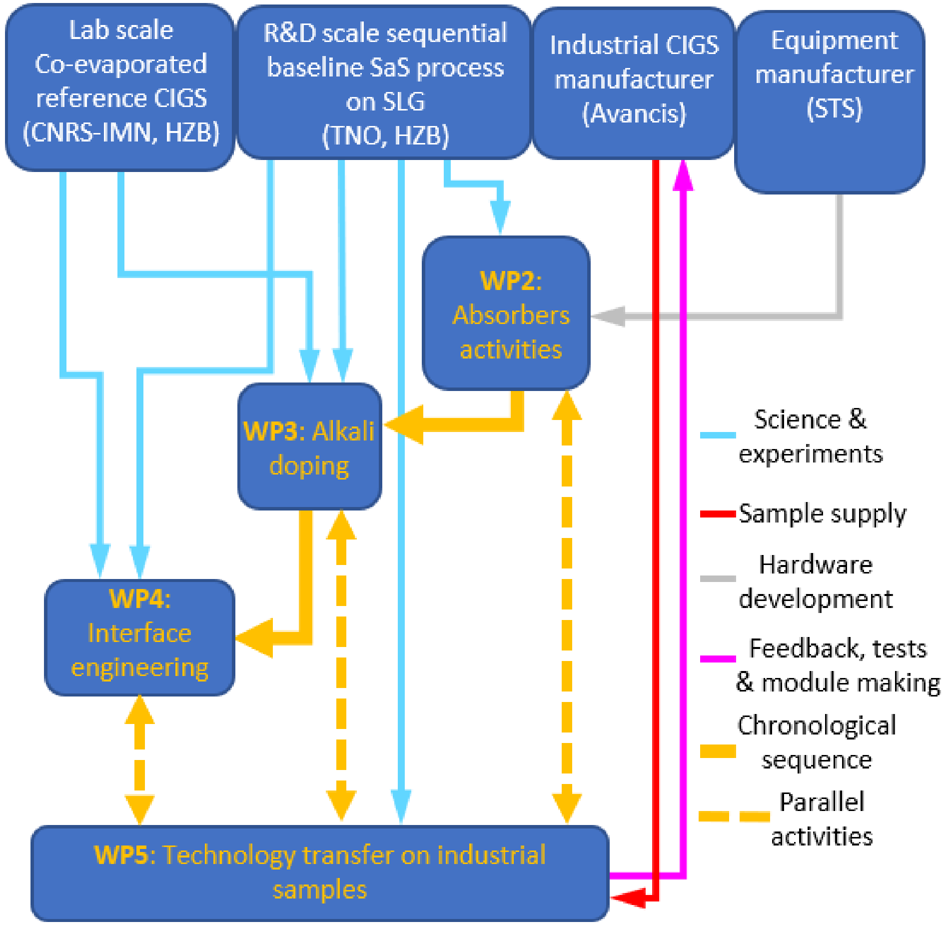
Project goals and partners

1. Determination of a best method for Na supply

2. Determination of a best method to supply the CIGSSe-absorber with heavier alkaline elements

3. Successful use of a dry buffer technology in combination with the established Na and heavier alkaline supply

4. Successful technology transfer to industrially manufactured CIGSSe absorber layers and components



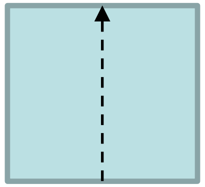
Results Smit Thermal lowcost CIGS platform

- Uniformity Selenium deposition 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 (see graphs for improvement in movement direction)

- Record 18.41% achieved in this project on Smit platform, externally certified by Fraunhofer ISE Freiburg.

- The low V_{OC} deficits achieved on the Smit platform relative to the band gap (lowest ≈375 mV, no PDT) suggest a high quality CIGSSe material prepared with the Smit Thermal Solutions tool.

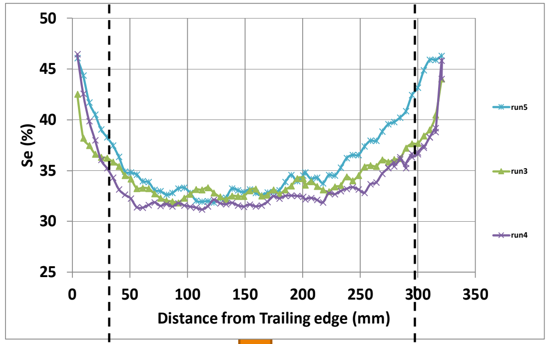
30 cm



30 cm

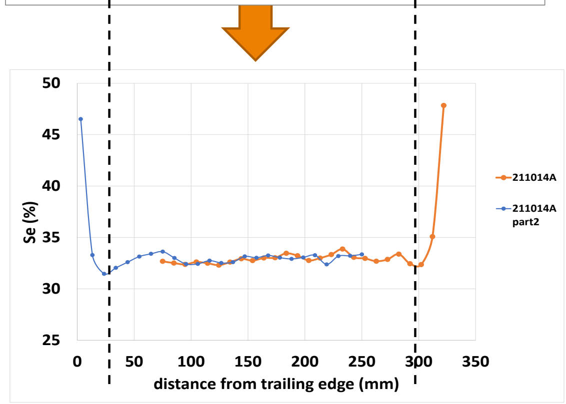
Deposited Se amount measurement

Project start



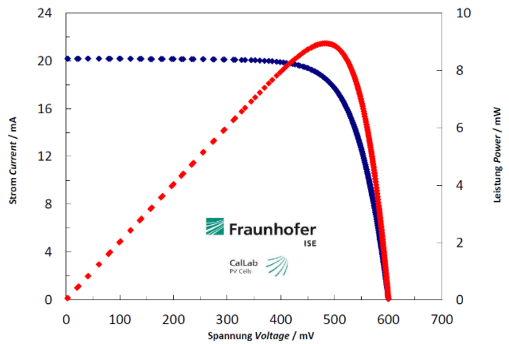
End of project

after multiple showerhead and sample carrier upgrades



Results alkali doping (PDT and Mo:K)

- HZB : Improvement of the best cell efficiency achieved with absorbers prepared in the Smit CIGS platform 18.4% by NaF + RbF PDT,



Sample	V_{OC} (mV)	J_{SC} (mA/cm²)	FF (%)	η (%)
No PDT	556	42.1	73.5	17.2
NaF+RbF	601	41.6	73.8	18.4

- CNRS-IMN : unique approach of 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)

  See Dissemination for peer-reviewed publications on this topic

PDT	V_{oc} (mV)	J_{sc} (mA/cm²)	FF%	η%
no PDT	675	34.7	71.7	16.8
CsF (S)	691	33.2	72.8	16.7
NaF/RbF (S)	707	34.2	73.1	17.7
RbF (S)	722	34.3	72.6	18.0
In+RbF (S)	716	34.6	74.8	18.5
In+RbF (S) With high Ga content during the 1st co-evaporation stage	735	33.9	77.6	19.3

- TNO : Improvement of the best cell efficiency by doping Potassium by industrially friendly sputtering as part of the back electrode, resulting in 17.9% on a steel substrate with co-evaporated CIGS

PDT	V_{oc} (mV)	J_{sc} (mA/cm²)	FF%	η%
no PDT	679	33.9	72.7	16.7
Mo:K Mo:Na on steel	704	33.4	76.1	17.9

Project progression vs. Planning & Lessons Learned

- Planning did not take COVID into account:
  - On-site project meetings had to be replaced by video conferences (w/ pros & cons)
  - Delays due to preventive measures, especially in 2020 (home-office)
  - Delays in particular related to upgrades and maintenance of hardware
- Development of a robust PDT process was much more difficult than anticipated
  - Previously accumulated knowledge on PDT for co-evaporated absorbers was not sufficient for a purely technological approach to the transfer to sequential absorbers
  - Experiments needing sample exchange between partners are challenging when PDT is involved
  - Sequential CIGS processes do not follow a purely modular principle : not only the SAS process itself, but back electrode, precursor stack, its thickness and elemental composition need to be taken into account

Transnational set-up

- It was experienced that the small consortium and less reporting overhead was very beneficial for knowledge exchange between the scientists
  - meetings and interaction focused on scientific information exchange
  - easy access to a transnational network with partners supporting eachother with knowledge and capabilities

Dissemination

- Polyxeni Tsoulka, Alexandre Crossay (from IPVF), Ludovic Arzel, Sylvie Harel, Nicolas Barreau, Alternative Alkali Fluoride post-deposition treatment under elemental Sulfur for high efficiency Cu(In,Ga)Se 2 -based solar cells, Progress in Photovoltaics Research and Applications, 835-842, Vol 30(8) 2022
- Polyxeni Tsoulka, Ludovic Arzel, Sylvie Harel, Alfons Weber, Thomas Niesen, Pablo Reyes-Figueroa, Hossam Elanzeery, Thomas Dalibor, Nicolas Barreau , RbF-related post-depostion treatments on Cu(In,Ga)(S,Se)2 asorbers : the role of chalcogen atmosphere, Applied Surface Science, vol 614 (2023), 155830

- Reyes Figueroa, Pablo; Alkali metal-treatments of low-bandgap Cu(In,Ga)(S,Se)2thin-films grown under atmospheric pressure. cVPVC2020 -Virtual Chalcogenide PV Conference online-Event, 25.05.2020 -28.05.2020 (2020)
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- Reyes-Figueroa, P.; Kodalle, T.; Bertram, T.; Villanueva-Tovar, A.; Waack, E.; Haberecht, R.; Kaufmann, C.A.; Schlatmann, R.; Klenk, R.: ALKALI POST-DEPOSITION TREATMENT OF CU(IN,GA)(S,SE)2SOLAR CELL ABSORBERS GROWN UNDER ATMOSPHERIC PRESSURE. In: 37th European Photovoltaic Solar Energy Conference and Exhibition. München: WIP, 2020. -ISBN 3-936338-73-6, p. 718-721
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- Reyes-Figueroa, Pablo; Bertram, Tobias; Waack, Erik; Haberecht, Ralf; Niesen, Thomas; Bombsch, Jakob; Alhasan, Shevan; Dalibor, Thomas; Bär, Marcus; Kaufmann, Christian A.; Klenk, Reiner; Schlatmann, Rutger: Alkali post-deposition treatment strategies for Cu(In,Ga)(S,Se)2solar cell absorbers, 8thWorld Conf. On Photovoltaic Energy Conversion, Milano, Italy, September 26th-30th2022
- Polyxeni Tsoulka; Alternative Alkali Fluoride post-deposition treatment under elemental Sulfur for high efficiency Cu(In,Ga)Se 2 -based solar cells. EUPVSEC-2021
- Polyxeni Tsoulka; Alternative Alkali Fluoride post-deposition treatment under elemental Sulfur for high efficiency Cu(In,Ga)Se 2 -based solar cells, JNPV-2020 (Dourdan, France)
- Simor, Marcel; Potassium-containing back electrode engineering for high performance CIGS solar cells, EUPVSEC-2021
- Aninat, Remi; High-performance CIGS solar cells on low-cost low carbon steel, 8thWorld Conf. On Photovoltaic Energy Conversion, Milano, Italy, September 26th-30th 2022