PVcomB
Competence Centre Thin-Film- and Nanotechnology for Photovoltaics Berlin

HZB Helmholtz Zentrum Berlin

Optimierung von CIGS-Solarzellen

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March 28th, 2019

Outline

- **Introduction to Cu(In,Ga)(S,Se)$_2$ solar cells**
  - Cu(In,Ga)(S,Se)$_2$ technology and advantages
  - Research on Cu(In,Ga)(S,Se)$_2$ solar cells
  - Solar cell fabrication process: PVcomB baseline
  - Characterization at PVcomB
- **Frameworks of industry-PVcomB collaboration**
  - National projects (TCO4CIGS, MyCIGS, NeuMaS, speedCIGS)
  - International projects (ACCESS)
  - Cooperation agreements
    - with equipment manufacturers (SMIT Thermal Solutions)
    - with module producers (AVANCIS),
- **Examples**
  - Dry Cd-free buffer for Cu(In,Ga)(S,Se)$_2$
  - Chalcogenization
  - Outdoor testing
- **Summary**

Introduction to $Cu(In,Ga)(S,Se)_2$ solar cells

Photovoltaic market

- c-Si (thickness >250µm).
- Thin film technology: CdTe, **$Cu(In,Ga)(S,Se)_2$** (thickness<3µm).
- Multijunctions, dye-sensitized, quantum dots…

$Cu(In,Ga)(S,Se)_2$ (CIGSSe) solar cell:

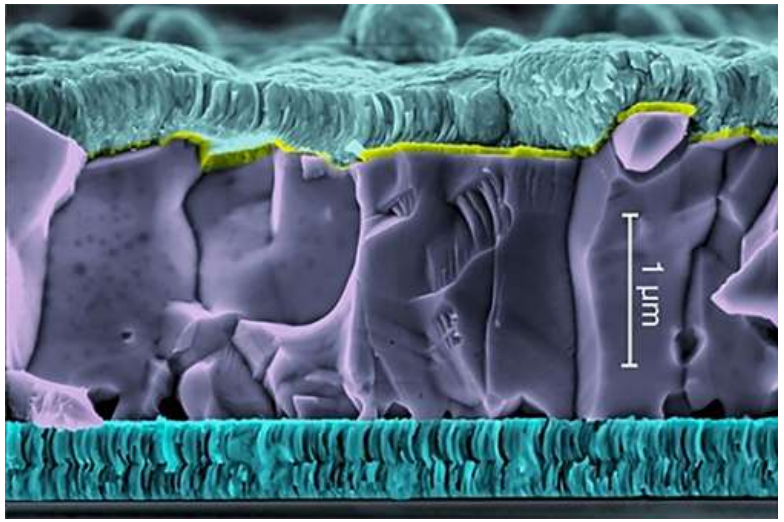
TCO

CdS (in yellow)

CIGSe

Mo

Glass



CIGS White Paper 2019

https://cigs-pv.net

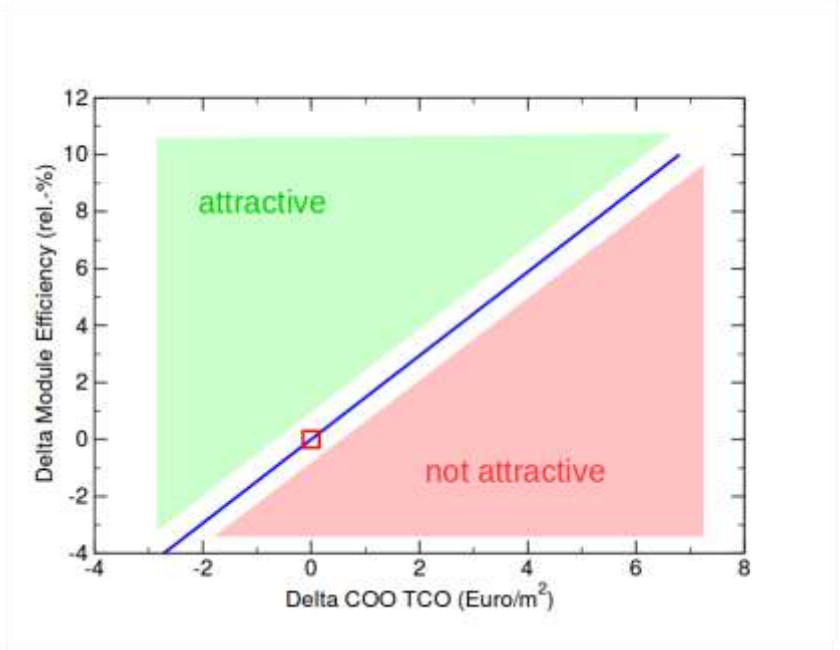
Advantages:

- High performance : solar efficiency in lab: **23.35%** [1]
- Low CO2 foot-print production.
- Building-integration
- Deposition on various substrates (flexible).
- Fabricated by a large range of techniques.
- Reduced manufacturing cost.

[1] Press release, Solar Frontier achieves world record thin-film solar cell efficiency of 23.35, Solar Frontier, 17th January, 2019.

Research on CIGSSe-based solar cells

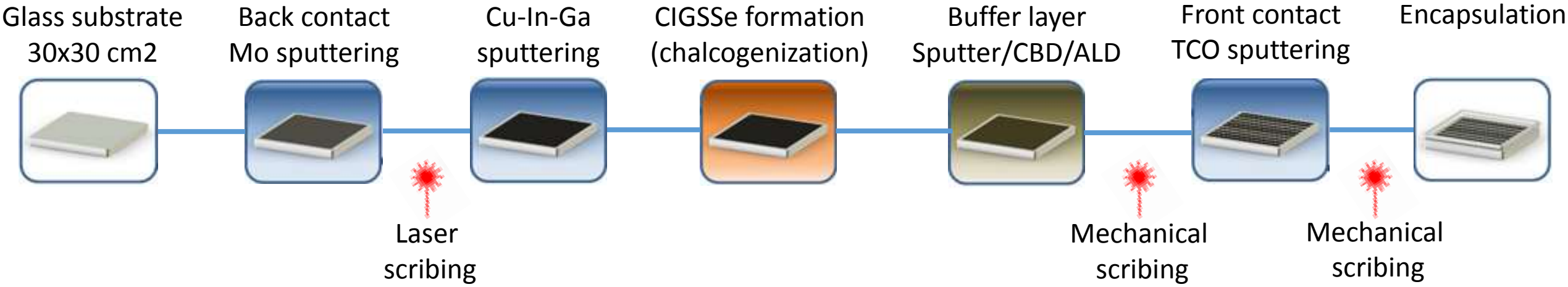
- High Technology Readiness Level
- Focus of research topics
  - Translate demonstrated high lab efficiency into mass-producible, low-cost solar modules
  - Reduce environmental footprint
  - Increase conversion efficiency



HZB approach and impact:

- Complete process sequences (baseline) and characterization => core lab
- Topics of relevance for industry addressing cost and efficiency
- Understand lab based approaches, adapt them to production requirements, scale-up and transfer them to industry
- Active role in consortia with academic and industrial partners

Introduction: Solar cell fabrication process



- Substrate: Sodalime float glass.
- Sputtering molybdenum back contact and Cu-Ga-In metallic precursors.
- CIGSSe formation in STS in-line atmospheric pressure tool:
  - Chalcogenization (selenium, sulfur).
- CdS buffer formation (sputtering, chemical bath deposition, atomic layer deposition) + i-ZnO (sputtered)
- ZnO:Al (sputtered)
- Standard module size 10x10 cm^2 and 30x30cm^2.

Introduction: Characterization methods

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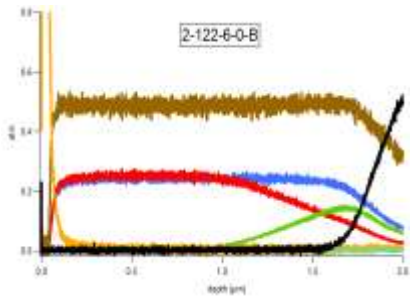
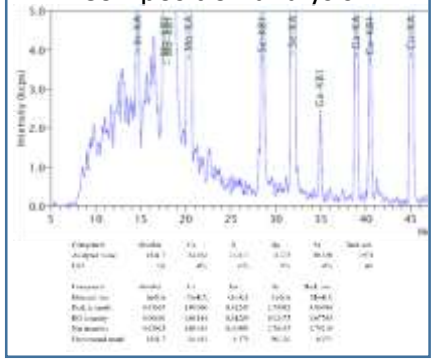
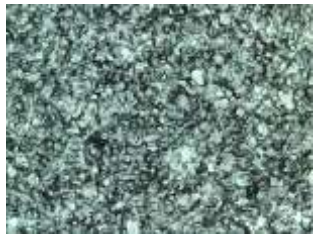
GD-OES
Depth profiling



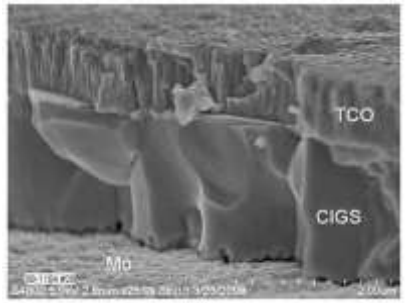
XRF
Composition analysis



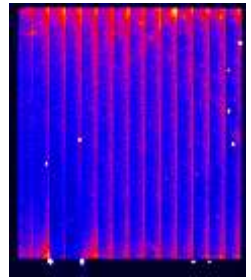
Laser-Confocal-Microscope
Surface Analysis



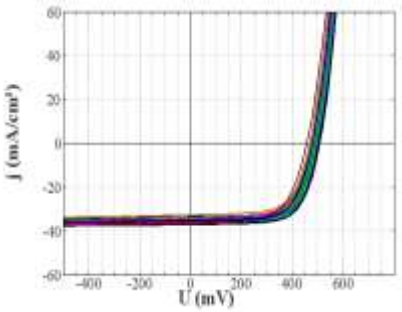
SEM
Depth profiling



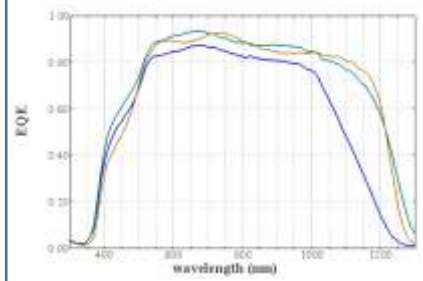
Thermography
Electrical Analysis



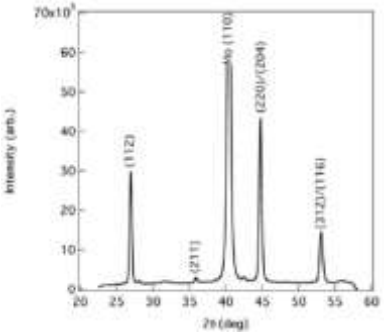
IV-Measurement
Electrical Analysis



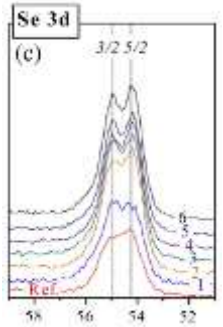
EQE-Measurement
Electrical Analysis



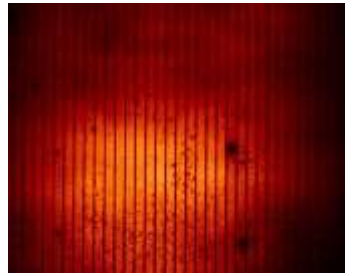
XRD
Structural Analysis



XPS
Surface Analysis



PL
Electrical Analysis



Also UV-Visible, Raman, among others.

Frameworks of industry-PVcomB collaboration

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National projects

- NeuMaS
- TCO4CIGS
- SpeedCIGS
- MyCIGS

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

AVANCIS CNBM

NICE SOLAR ENERGY

MBE KOMPONENTEN | DR. EBERL

International projects

- ACCESS

SOLAR-ERA.NET

SMIT THERMAL SOLUTIONS

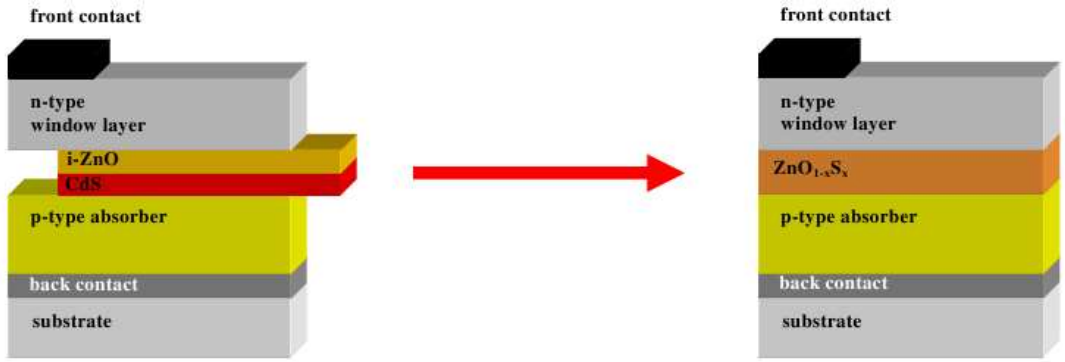
Cooperation agreements

- Feasibility studies
- Troubleshooting

SENTECH Erfolg durch Leistung

SOLAYER

Example 1: Dry Cd-free buffer for CIGSSe



- Substitution of CdS or In_xS_y/i-layer stack by a single sputtered Zn(O,S) layer to avoid toxic materials, reduce process complexity, and fabrication cost.

2010 — 2016 — AVANCIS in-house development — 2018

Fundamental science (material characterization)

Applied science (experimental solar cells)

Technology transfer (30x30 cm2 modules)

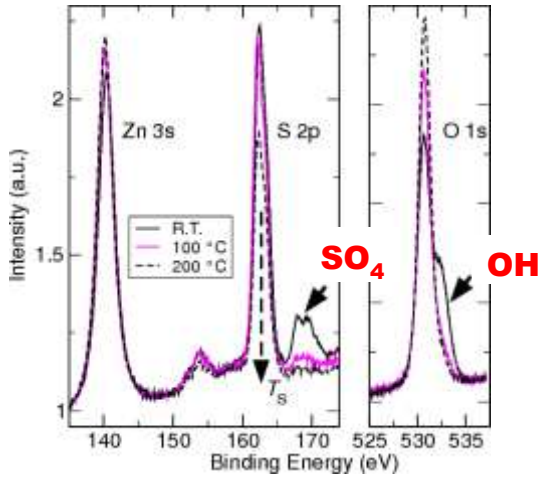
AVANCIS CNBM

Example 1: Dry Cd-free buffer for CIGSSe

- Reactive sputtering (ZnS target) in CISSY System (2.5x2.5 cm²)
  - Optical, structural and surface properties ZnO => ZnS
  - Band alignment to CIGSSe
  - First small area cell
- Sputtering from mixed target (5x5 cm², static substrate)
  - Successful tests on industry absorbers
  - Efficiency potential demonstrated on HZB lab-scale absorber
  - First mini-modules
- Scaling up (inline 30x30 cm², moving substrate)
- Technology transfer

Example 1: Dry Cd-free buffer for CIGSSe

Phys. Status Solidi RRL **4** (2010) 109



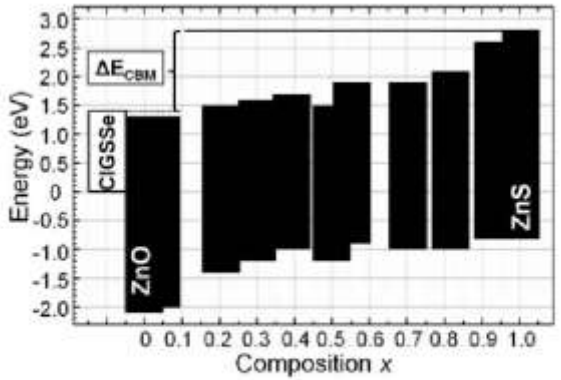
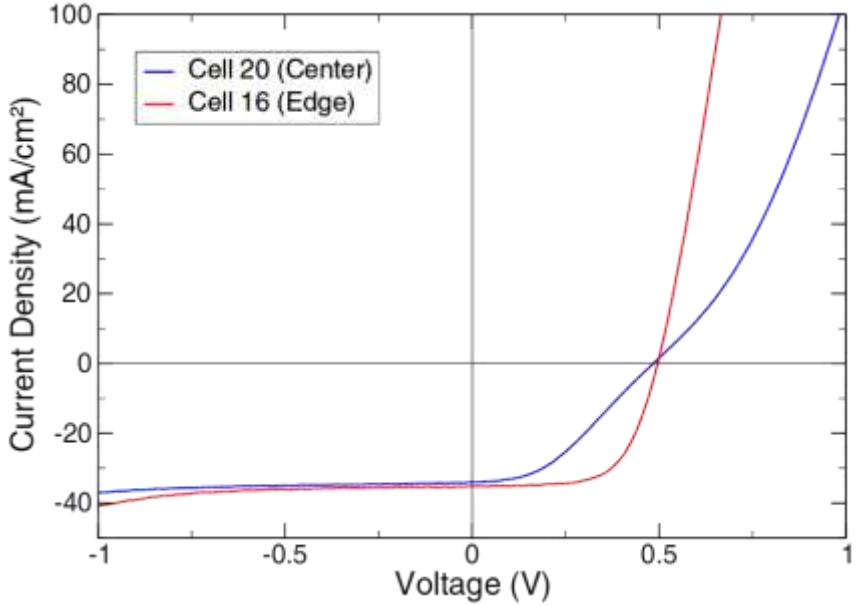


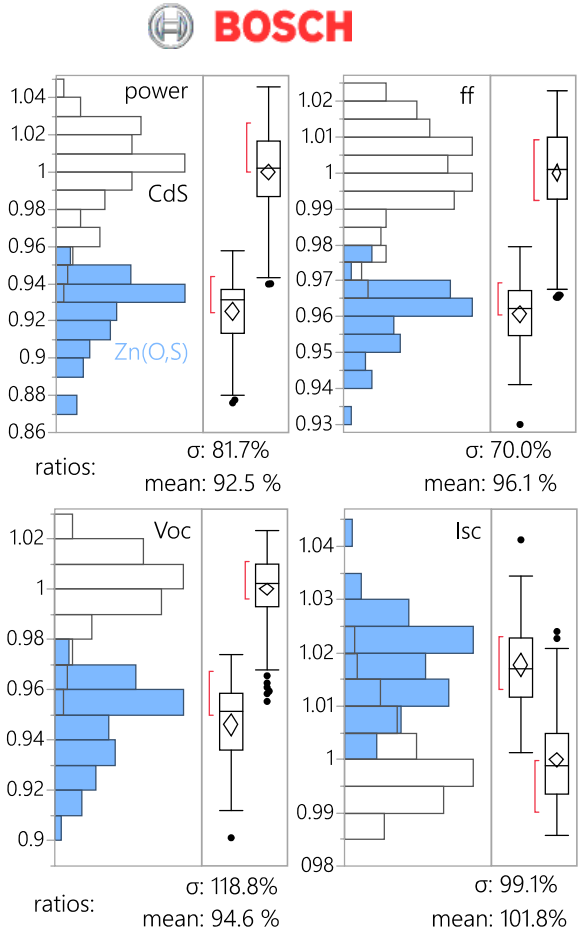
Figure 2 Schematic flat band diagram of the studied Cu(In,Ga)(Se,S)$_2$/ZnS$_x$O$_{1-x}$ heterojunctions as a function of composition x of the reactively sputtered ZnS$_x$O$_{1-x}$.

Phys. Status Solidi RRL **6** (2012) 294



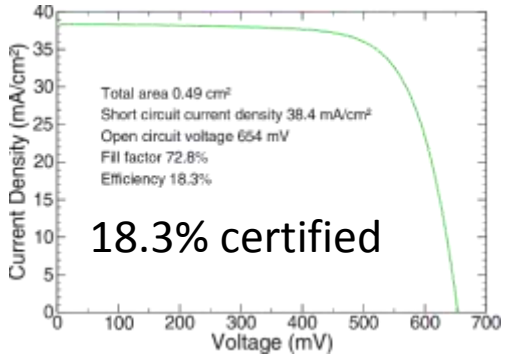
- Process window
- Statistical evaluation

A. Wachau (Bosch) *et al.*, Prog. Photovolt: Res. Appl. **25** (2017) 696



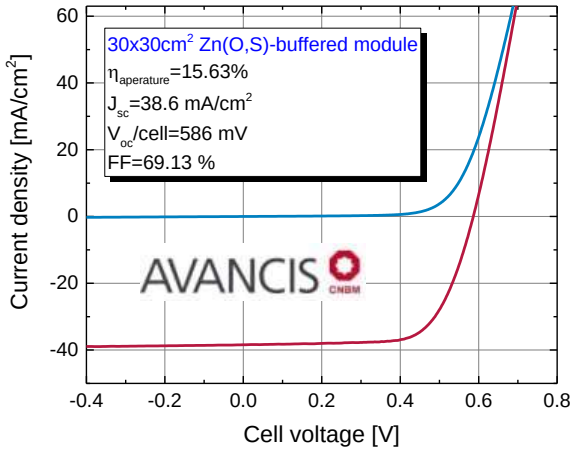
Example 1: Dry Cd-free buffer for CIGSSe

All layers HZB – 0.5 cm²



Prog. Photovolt: Res. Appl. **22** (2013) 161

Buffer HZB; absorber &TCO AVANCIS

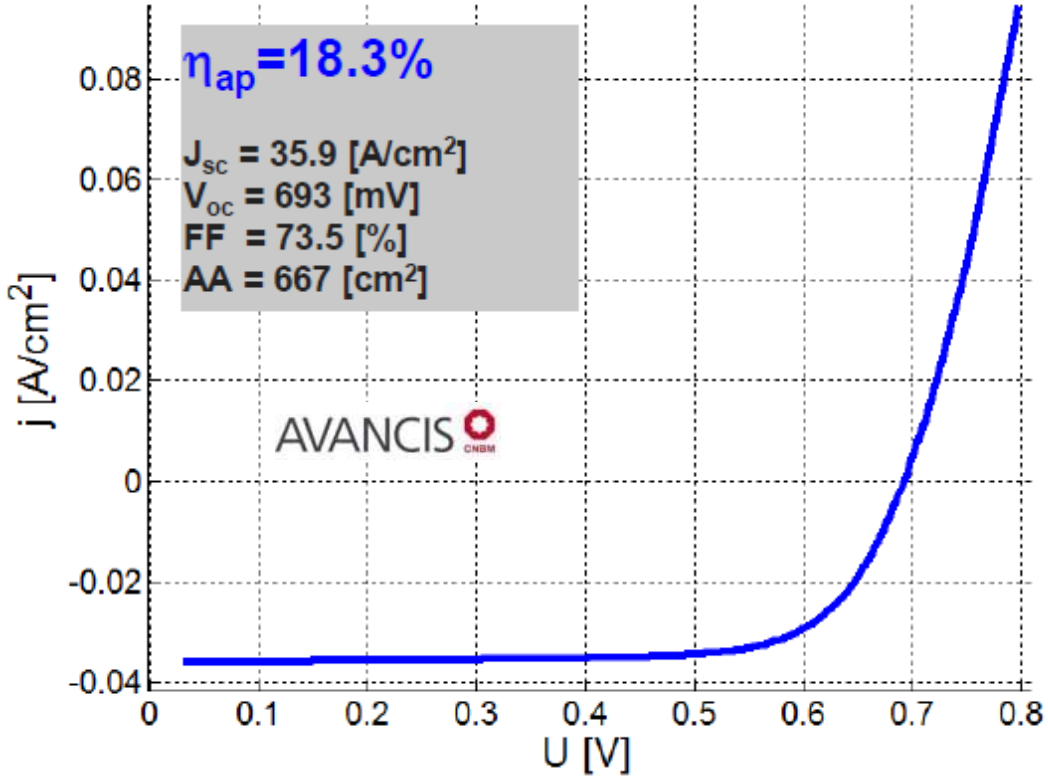


M. Algasinger (AVANCIS) *et al.*, Thin Solid Films **633** (2017) 231

All layers AVANCIS – 667 cm²

AVANCIS in-house development

Sputtered-Zn(O,S) buffer layers in CIGS modules at 18% efficiency.
35th EU PVSEC, 24th-28th September, 2018, Brussels.



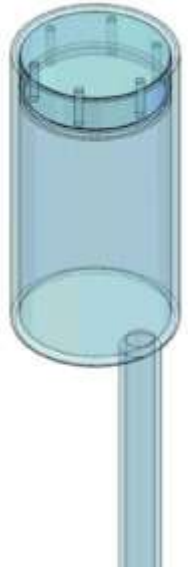
Example 2: Chalcogenization of metallic precursors

- ACCESS project SOLAR-ERA.NET
  - Fast sequential preparation of CIGSSe by chalcogenization of metal precursors using Se/S/H_2S (**no H_2Se**) at **ambient pressure**.
  - Reduce CapEx

SMIT THERMAL SOLUTIONS

SMIT Thermal Solutions atmospheric chalcogenization in-line machine.

MBE KOMPONENTEN | DR. EBERL



MBE Komponenten selenium plasma source.

Partnering research institute:

SOLLIANCE THIN FILM SOLAR RESEARCH

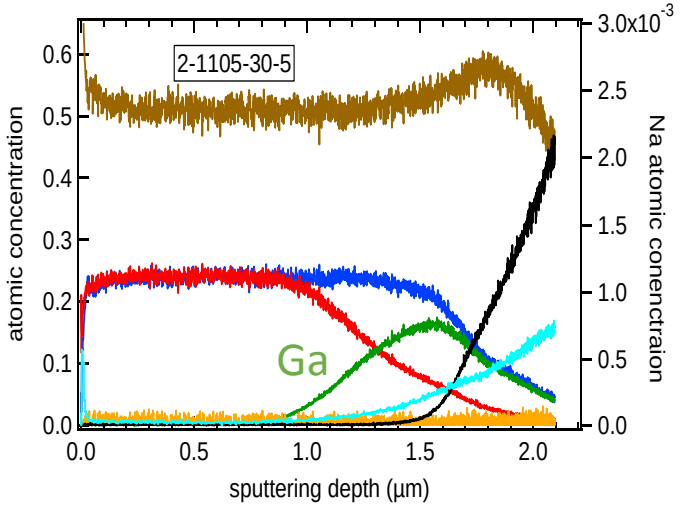
External observer & consulting:

AVANCIS CNBM

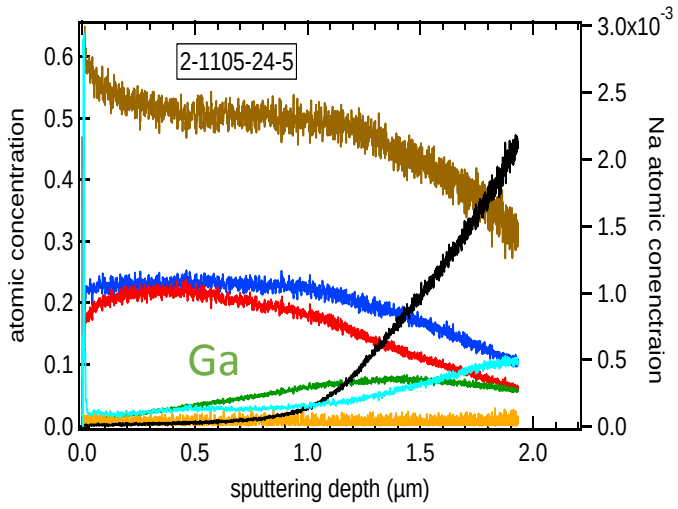
Example 2: Chalcogenization of metallic precursors

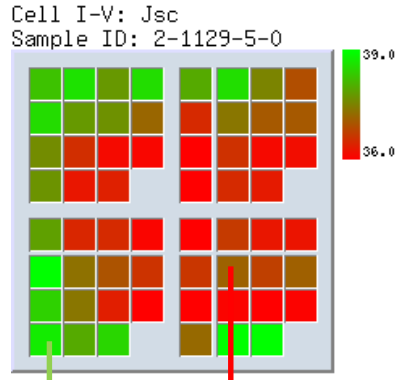
- Industrial process development issues
  - Process compatibility
  - Compositional depth profile
    - Band gap depends on Ga/(Ga+In) and S/(S+Se) ratios
  - Homogeneity

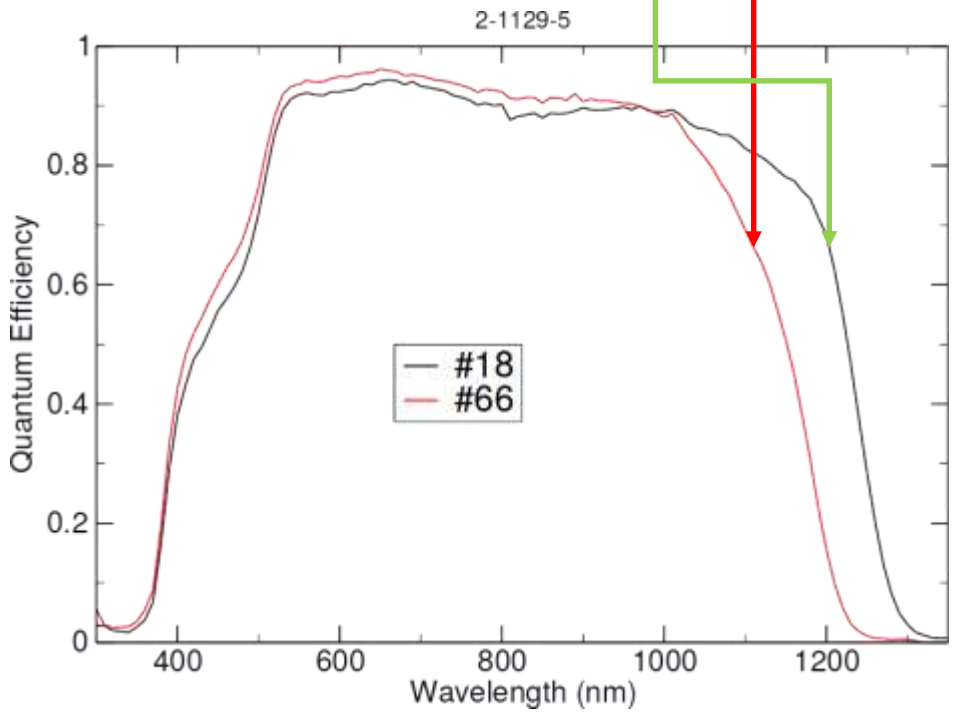
Zone 4 cracker @ 600°



Zone 4 cracker @ 420°







Example 3: Outdoor Testing

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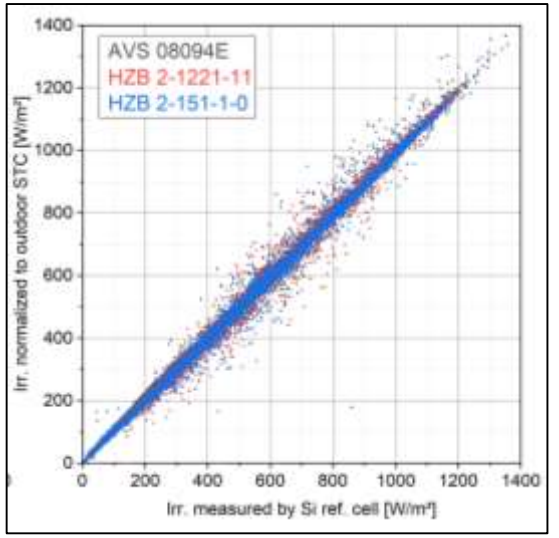
MyCIGS project

AVANCIS CNBM



Summary

- PVcomB is an institute with a wide experience in CIGSSe research and industry collaboration
- All processes available on at least 30x30 cm^2
- PVcomB is able to characterize materials, solar cells, and solar modules with a wide variety of techniques
- Several frameworks for cooperation with industry, suitable for:
  - Joint development
  - Feasibility studies
  - Trouble shooting