Solar cell research at the laboratory for Thin Films and Photovoltaics at Empa

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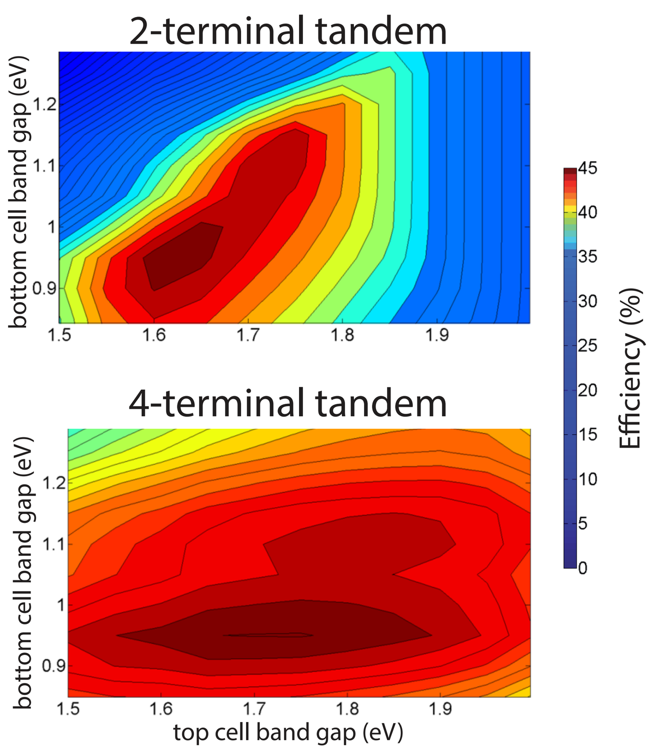
Empa
Materials Science and Technology

Research Focus

The laboratory for Thin Films and Photovoltaics is working on thin film solar cells based on chalcogenide (CIGS, CZTS) and perovskite absorber materials.

The primary focus is the development of flexible solar cells and all-thin-film tandem devices.



By using a stack of two solar cells of different band gaps, higher efficiencies (η > 40 %) can be achieved

CIGS thin film bottom cell:
- high efficiency (23.35 %)
- tunable narrow band-gap (1.0 - 1.3 eV)
- potential for low production cost
- allows flexible substrates

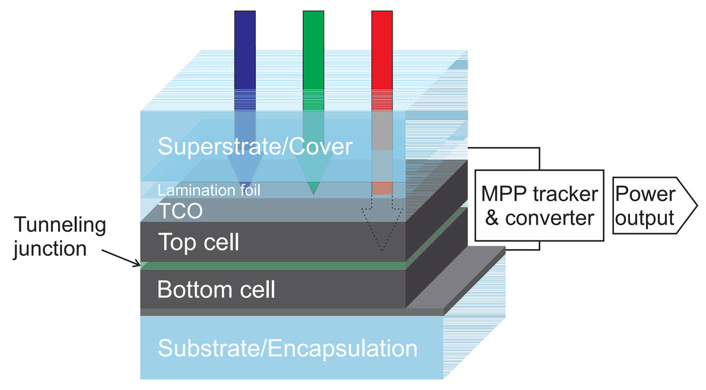
Perovskite thin film top cell:
- high efficiency (25.2 %)
- low deposition temperature
- tunable wide band-gap (1.55 - 1.7 eV)
- allows flexible substrates

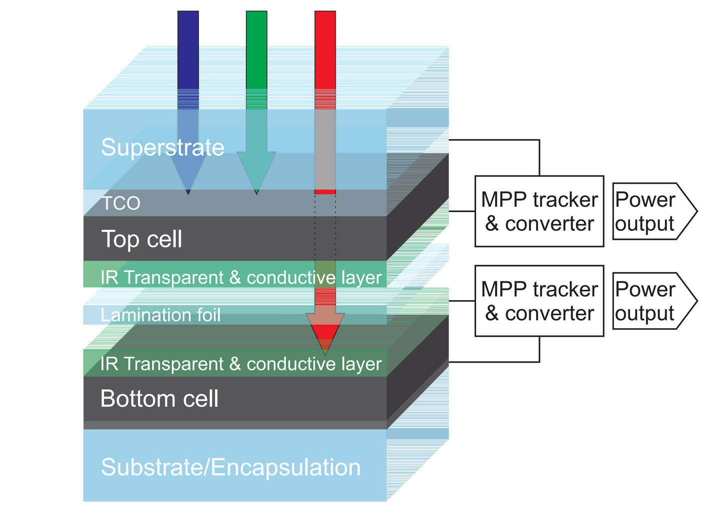
Tandem solar cells are the most promising technology to further increase the efficiency of solar cells beyond the classical detailed balance single junction limit of ~30 %.

Fundamental approaches for dual junction tandems :

2-terminal (monolithic) tandems:
- Reduced material use and optical losses
- Current matching necessary
- Increased growth complexity due to constraints posed by the sub-cells (roughness, temperature)
- Need for tunneling junction / recombination layer

4-terminal tandems:
- High flexibility in composition and production
- Improved stability to variable spectrum and asymmetric degradation of sub-cells
- Increased optical losses (TCO) and material usage
- Additional electrical circuit necessary



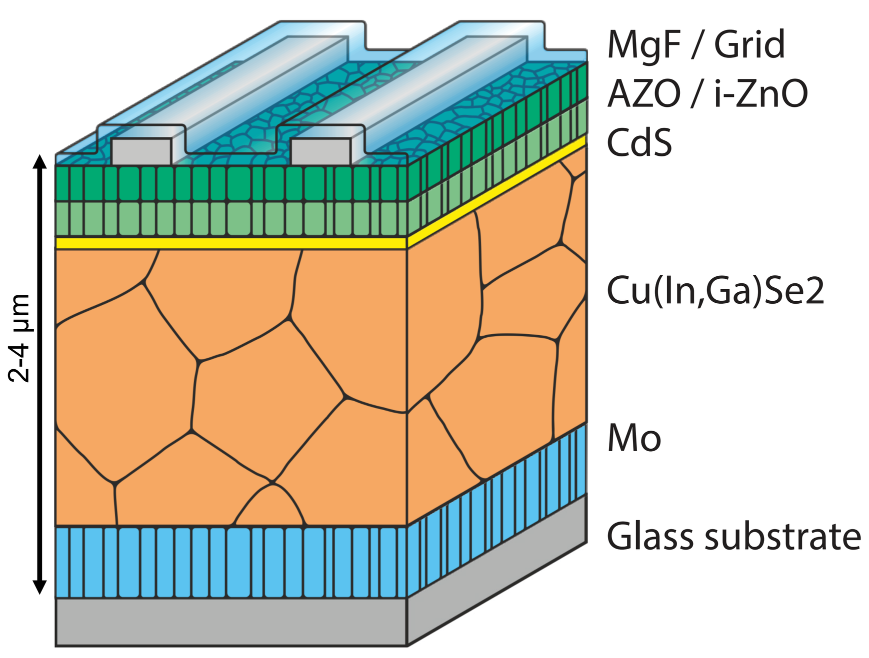


Results

CIGS bottom cell

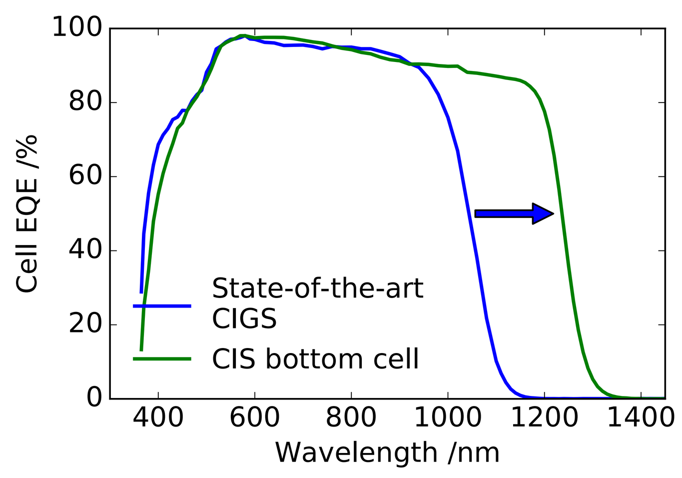
Development of bottom cell with band gap of 1.0 eV

CIGS structure



WHY ARE WE INTERESTED?

Traditional CIGS has a bandgap that is too high for the optimal combination in a tandem device!



PV parameters of notable CIGS cells

	Band gap (eV)	V_{OC} (mV)	J_{SC} (mA/cm^{-2})	FF (%)	Eff (%)
CIGS on glass [1] (Solar Frontier)	1.08	734	39.6	80.4	23.35*
Flexible CIGS [2] (Empa)	1.14	734	36.7	77.2	20.8*
CIGS on Steel (Empa)	1.09	703	38.5	74.4	20.2*
Narrow BG CIS [3] (Empa)	1.00	609	42.3	74.6	19.2

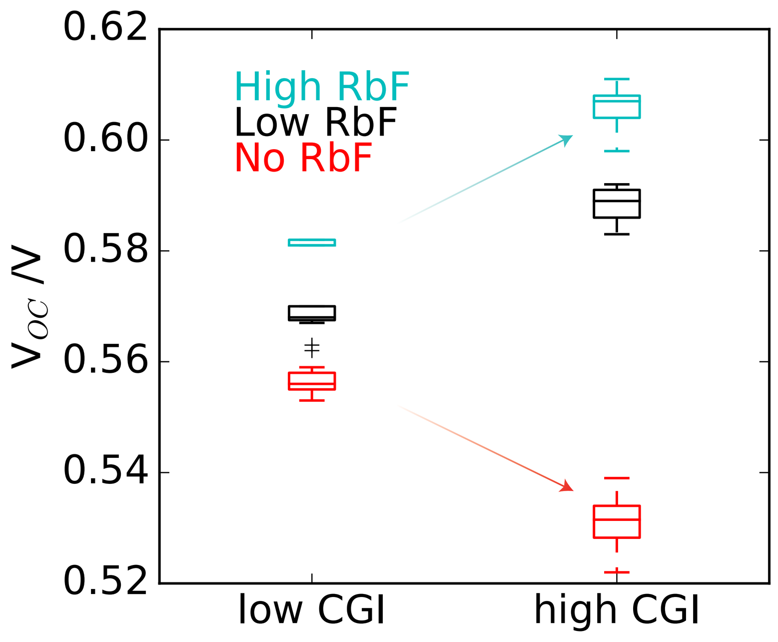
* Externaly certified values

[1] Nakamura et al., IEEE Journal of Photovoltaics, vol. 9, no. 6

[2] Carron et al., Advanced Energy Materials, vol. 9, no. 24

[3] Feurer et al., Advanced Energy Materials, vol. 9, no. 35

Improvemed stoichiometry in CIS



- State-of-the-art CIGS shows high conversion efficiency (20.8 %) on flexible polyimide substrate
- 19.2% efficient CIS cell with 1.00 eV band gap achieved on glass substrate

Main improvements:
- Reduced recombination at back contact, bulk and front interface
- V_{OC} of cells considerably enhanced

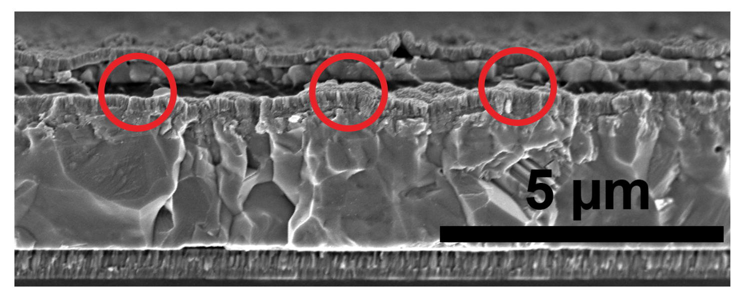
All-vacuum-processed perovskite top cell

Perovskite top cell development without spin coating

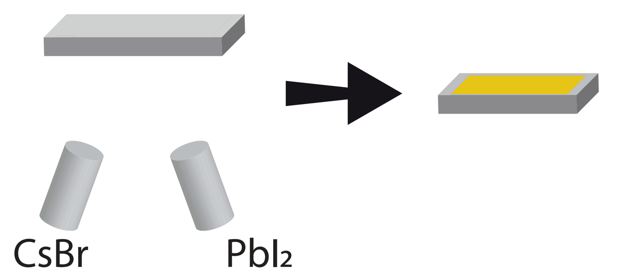
Reference	Potential replacements
AZO	
ZnO-NP	SnO₂ (ALD)
PCBM	C60 (evap.)
$(Cs,FA)Pb(I,Br)_3$	
PTAA	NiO (sput.)/ MnS (evap.)
ITO	
Glass	PET

WHY ARE WE INTERESTED?

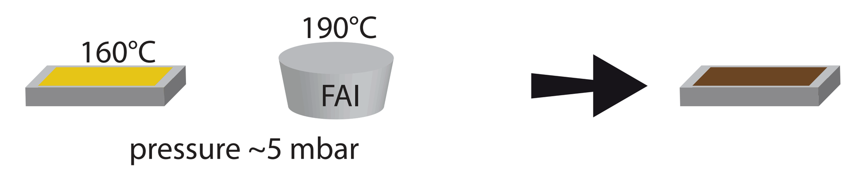
Perovskite solar cells deposited using wet chemistry processes have problems to evenly cover rough surfaces.
This leads to shunting in the top cell and prevents monolithic devices from operating at optimal conditions.



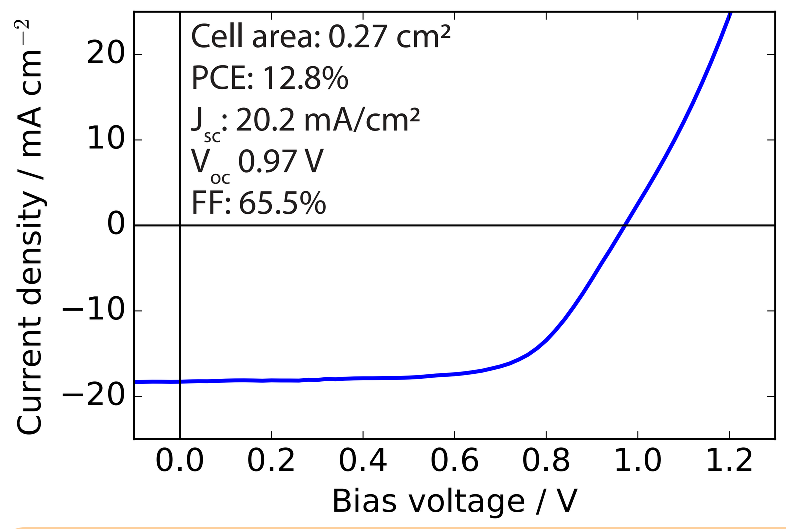
Deposition of CsBr:PbI_2 by PVD



Formation of perovskite by CVD process



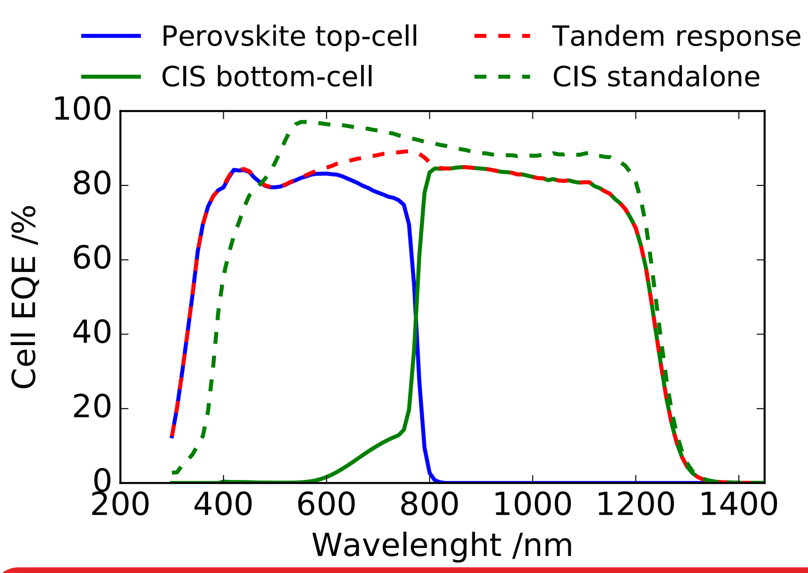
Cell with vacuum deposited absorber (J-V)



Semitransparent perovskite solar cells

- Two-step vacuum process for absorber deposition implemented
- Alternative charge extraction layers identified and under evaluation

Tandem device performance



4-terminal perovskite/CIS tandem solar cells

	V_{OC} (mV)	J_{SC} (mAcm^{-2})	FF (%)	Eff. (%)
CIS standalone	597	42.3	74.0	18.7
Perovskite top-cell (bwd)	1'034	20.79	79.8	17.2
Perovskite top-cell (MPP)				16.9
CIS bottom-cell	565	19.4	74.2	8.1
4-terminal tandem				**25.0**

Tandem with perovskite top cell from partner TNO / Solliance.

Summary and Outlook

- 19.2% efficient CIS based solar cells with lowest bandgap (1.0 eV) have been achieved
- CIS cells show improved V_{OC} and charge carrier collection
- Bottom cell current in 4 terminal configuration can reach values comparable to $FAPbI_3$ based top cells
- Vacuum-based perovskite absorbers with good phase purity and homogeneity have been achieved
- 25 % efficiency demonstrated in 4-terminal tandem configuration

- Fill factor of both cells is still poor and needs further improvement
- ETL/HTL still spin coated, development of vacuum processed extraction layers ongoing
- Demonstrate monolithic 2-terminal tandem devices

Acknowledgement

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