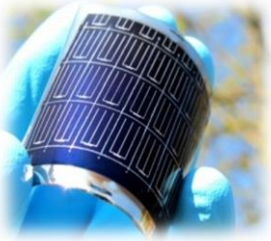
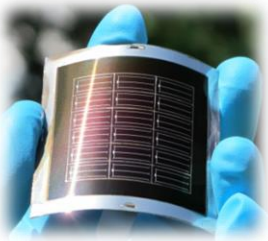
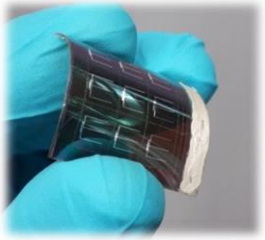




Empa
Materials Science and Technology

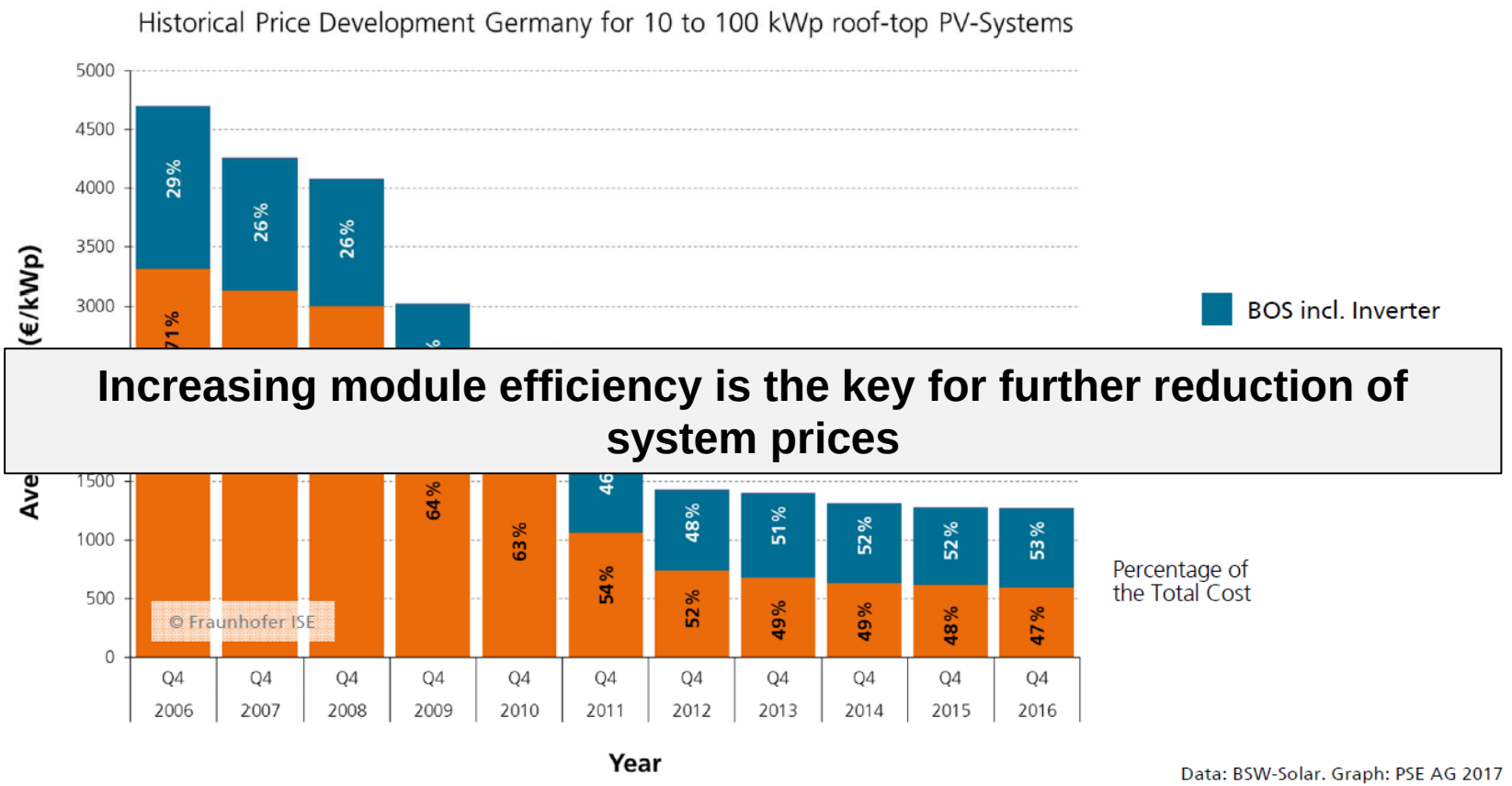
Insights to high efficiency CIGS thin-film solar cells and tandem devices with Perovskites

Dr. Stephan Buecheler

Contact: stephan.buecheler@empa.ch Direct: +4158 765 6107

Laboratory for Thin Films and Photovoltaics, Empa - Swiss Federal Laboratories for Materials Science and Technology,
Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland;

Average Price for PV Rooftop Systems in Germany
(10kWp - 100kWp)

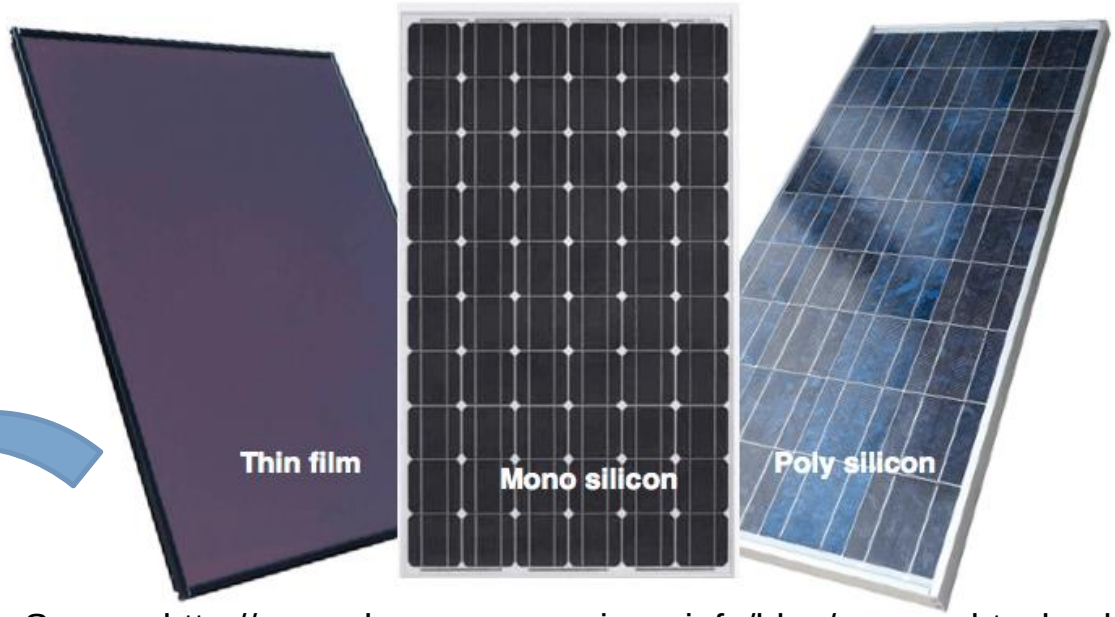


Increasing module efficiency is the key for further reduction of system prices

© Fraunhofer ISE

Fraunhofer ISE

©Fraunhofer ISE: Photovoltaics Report, updated: 12 July 2017

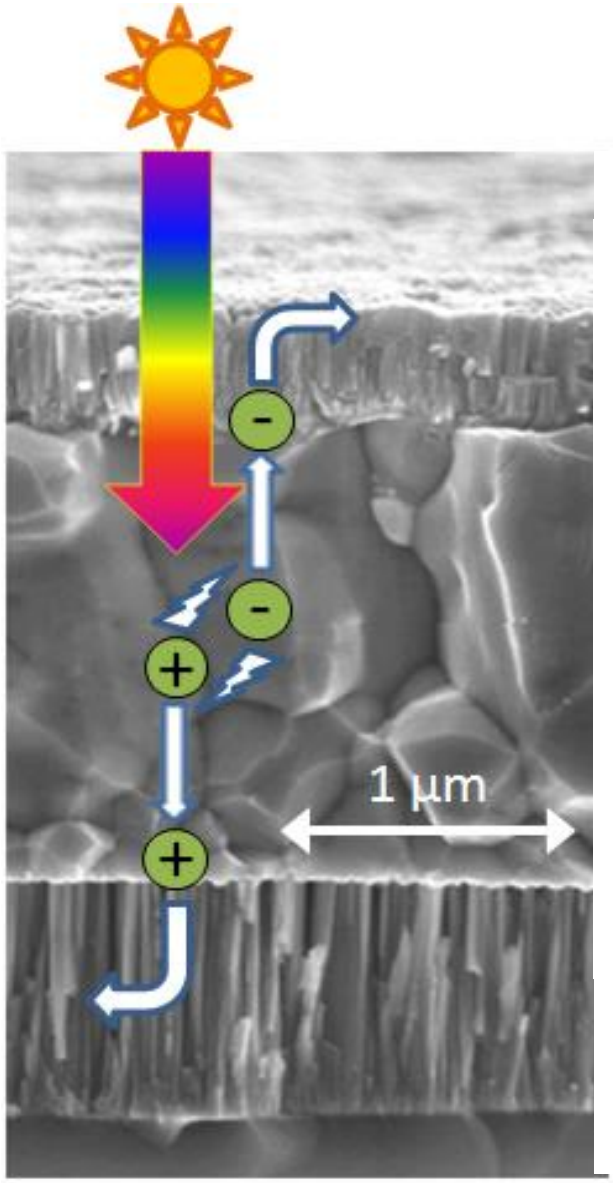


Source: http://www.cleanenergyreviews.info/blog/pv-panel-technology

Opportunities with Thin Film PV

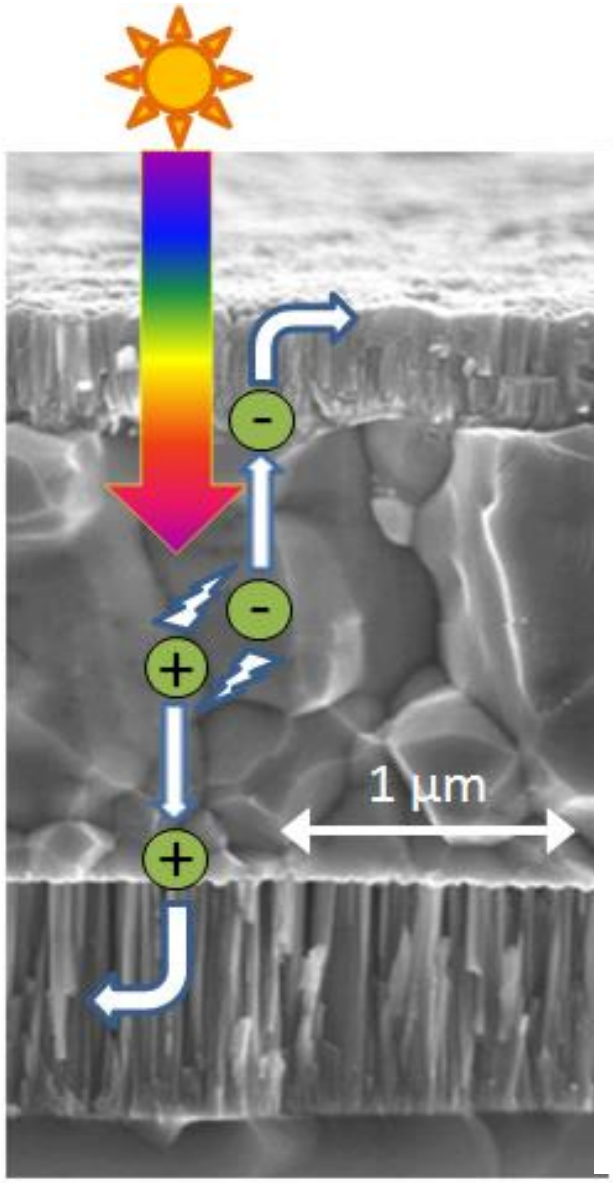
- Shorter Energy Payback Time
- Better Energy Yield
- Lower Carbon footprint
- Enabling efficiency improvements of Si wafer cells
- Innovative production & applications
- Better aesthetics

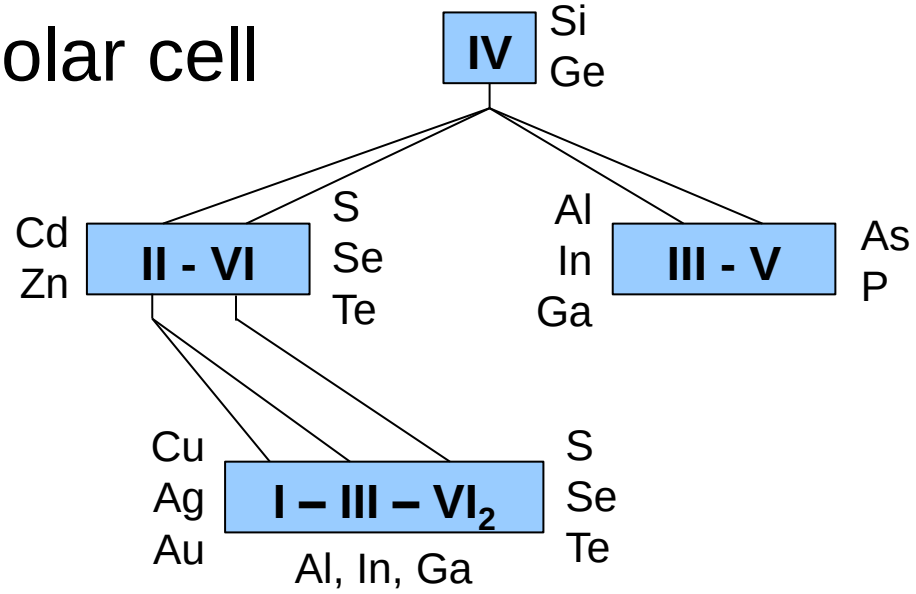
Thin film solar cell



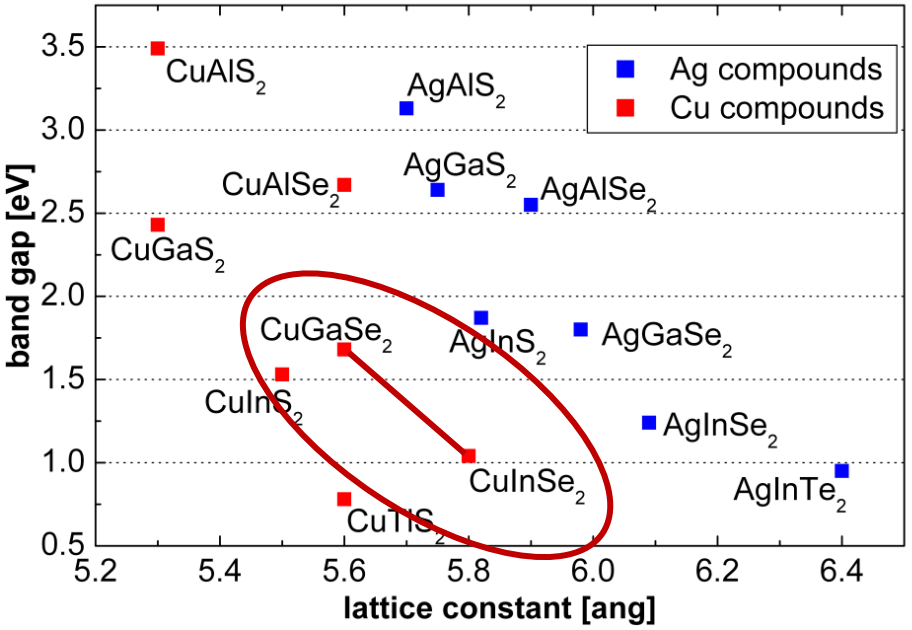
Different layers and configurations

Thin film solar cell





Band gap engineering by alloying



CIGS thin film solar module

Production capacity of >1 GW from 3 manufacturing plants

19.2% conversion efficiency on 30cm x 30cm substrate in March 2017

19.8% conversion efficiency on 7cm x 5 cm substrate in March 2017

23.3% conversion efficiency on a ~0.5cm² CIS cell in November 2017

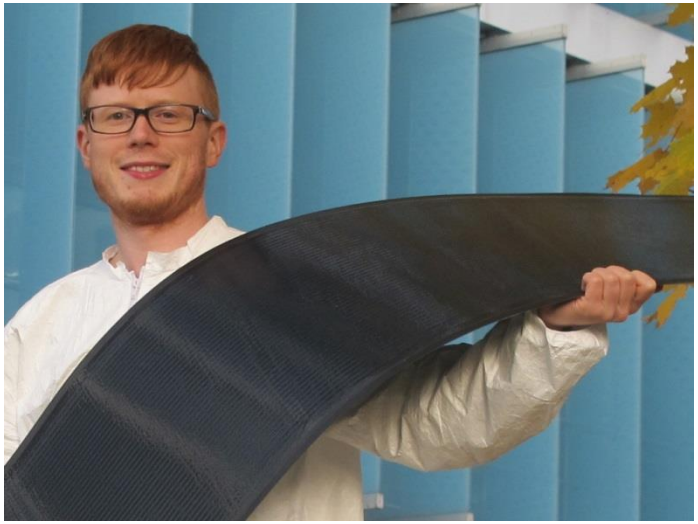
2015-07-23

Solar Frontier Surpasses 3 GW of Global CIS Module Shipments

http://www.solar-frontier.com/eng/news/2015/C047775.html

Applications of CIGS: from buildings to utility scale ground mount

Building integrated CIGS modules in Sweden (Solibro)



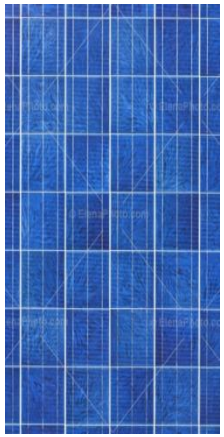
Lightweight flexible CIGS module (Flisom)

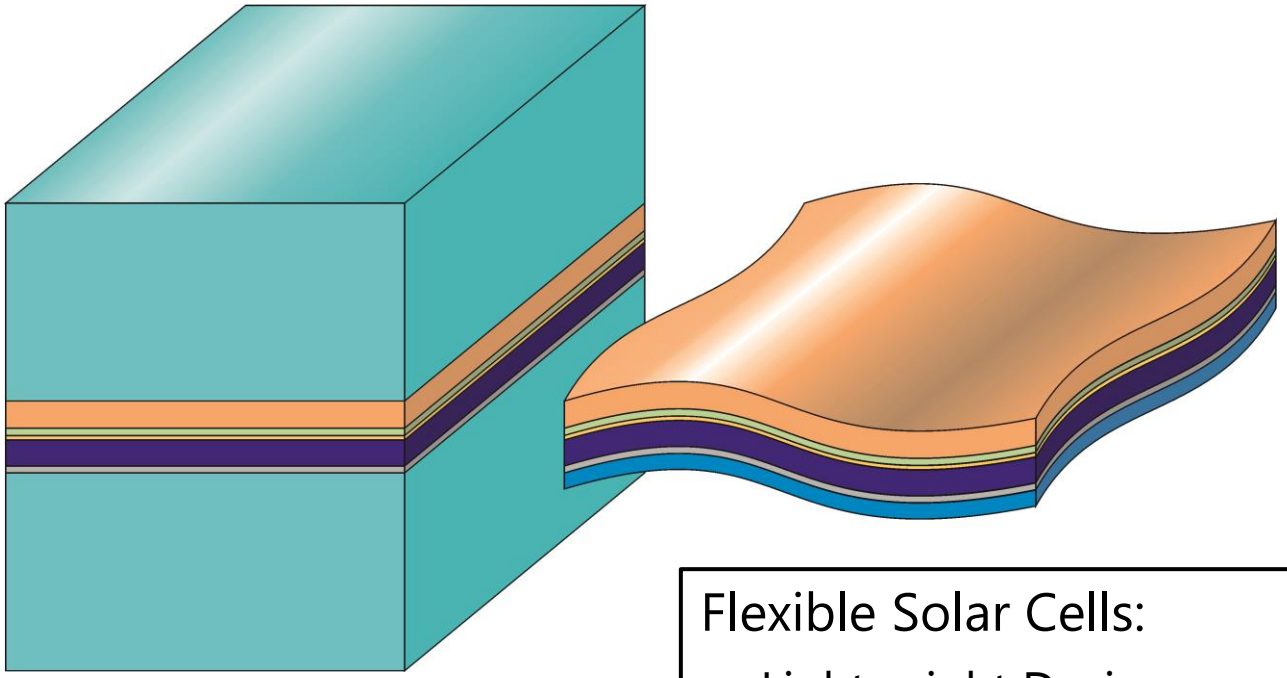
Building integrated CIGS with 500 m² (Manz AG)

3.1 MWp of CIS modules near Bonnhof, Germany (Solar Frontier)

Source: http://cigs-pv.net/cigs-thin-film-projects/

Why are we interested in flexible PV modules?





Si wafer or thin film PV on glass:

Heavy & Rigid

Flexible Solar Cells:

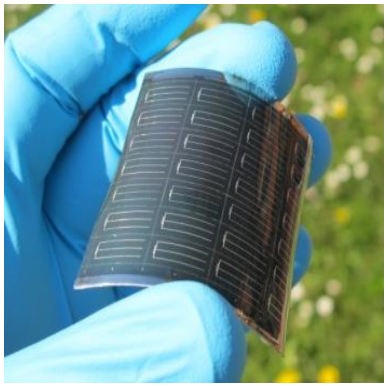
- Lightweight Devices
- Potential to reduce grey energy
- Portable and mobile applications
- Building-integrated PV
- **Roll-to-roll manufacturing**

Thin films (coatings) on flexible substrate are everywhere around us

Pictures for educational purposes; Source: different websites

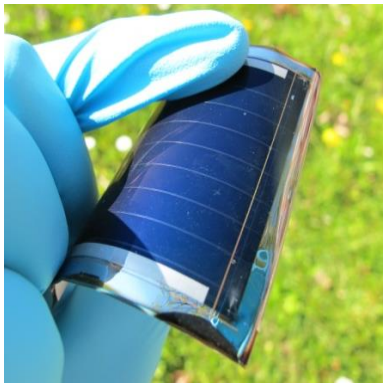
Flexible and lightweight solar cells / challenges*

Solar cells



- How to add Alkaline/doping elements
- limited processing temperature
- Residual stress management
- Adhesion esp. CIGS on Mo or CdTe on BC
- How to adjust compositional grading (CIGS) or recrystallization (CdTe)
- …

Mini-modules



- All laser based interconnection of cells to modules
- Bendable current collectors
- How to manage shrinkage or elongation of substrate
- …

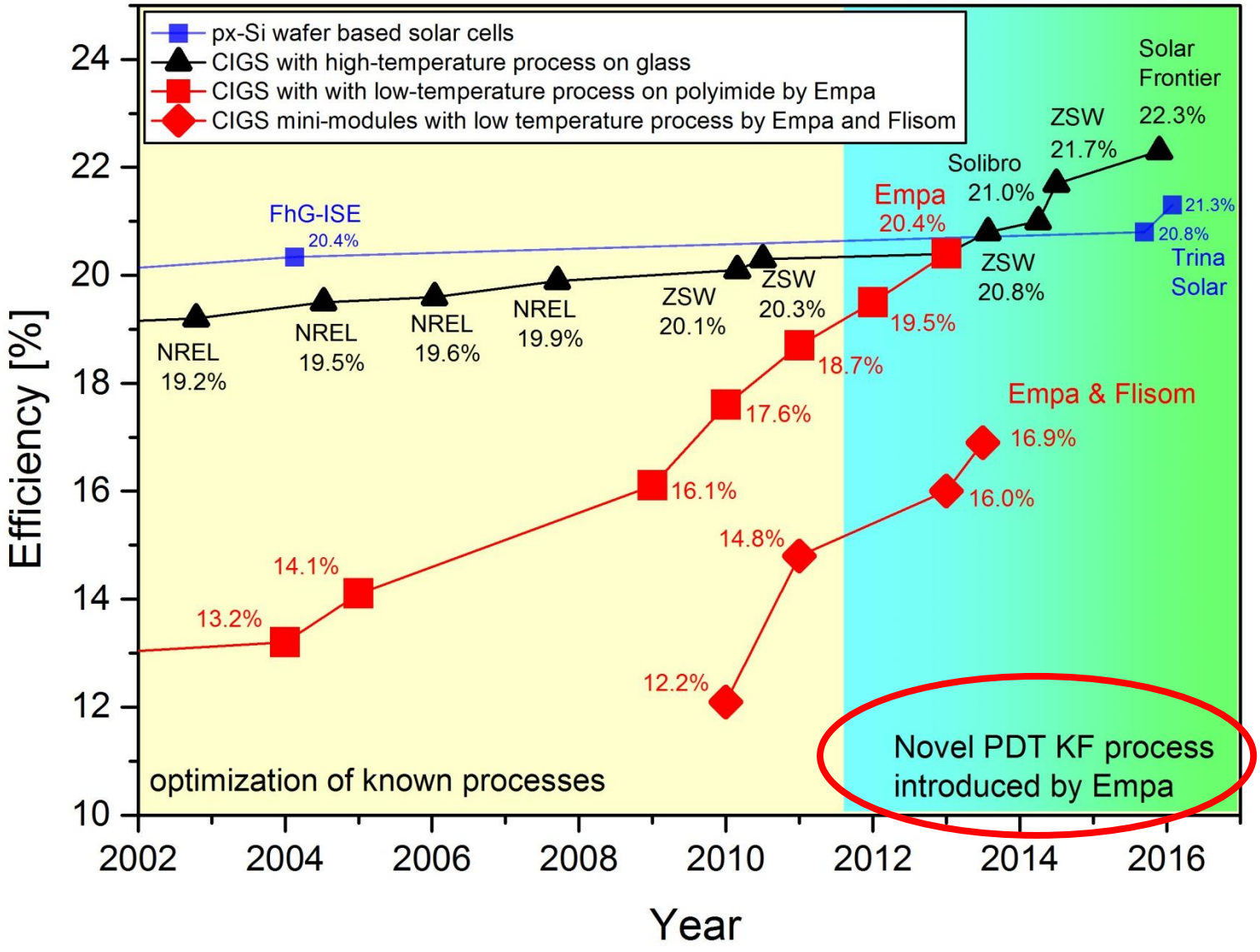
Solar modules

- Transfer of process to R2R inline equipment
- Development deposition equipment
- In-situ process control on non-flat substrates
- Flexible encapsulation
- …

Which substrate, which process, …

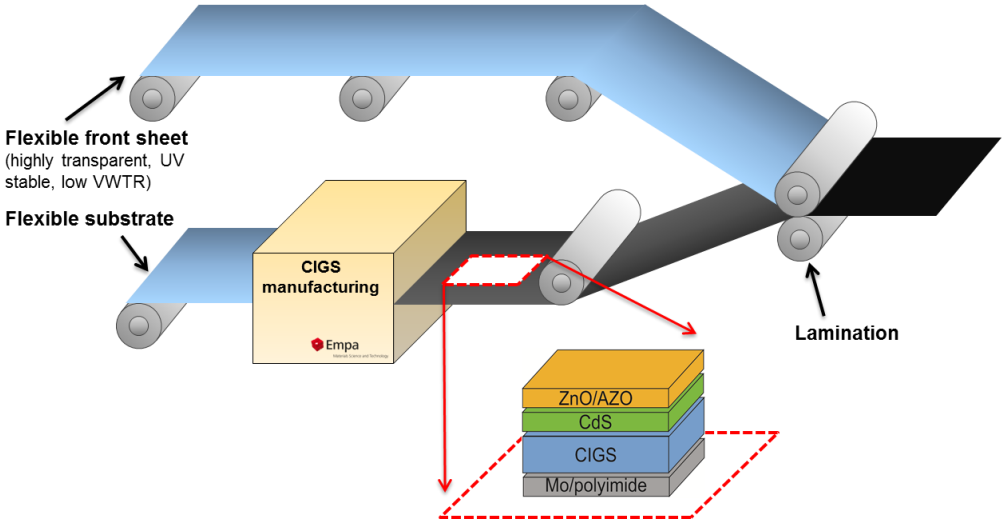
* List is not complet

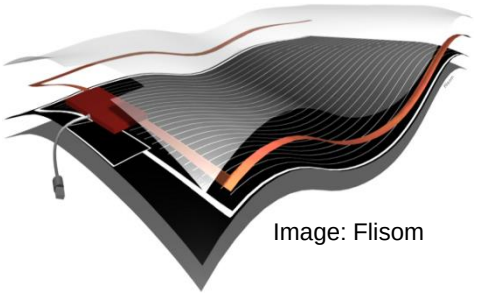
CIGS solar cells and mini-modules / state-of-the-art

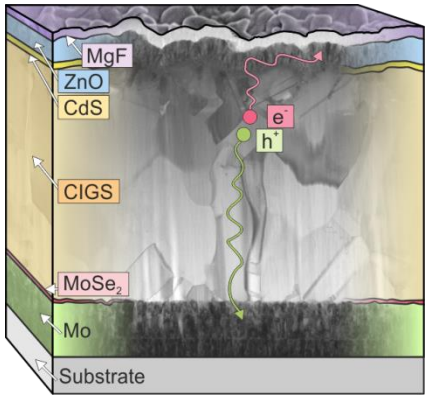


23.3% SF
22.8% SF
22.6% ZSW

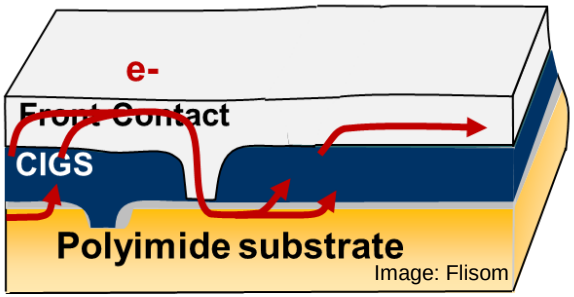
Lightweight Thin Film PV Modules







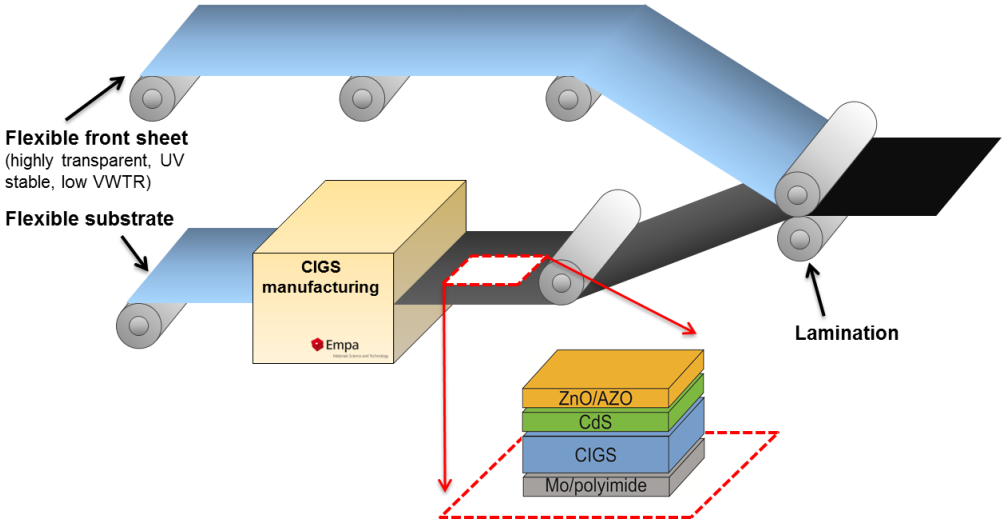
Deposition of multilayer stack



Monolithical interconnection + application of bus bars

Lightweight Thin Film PV Modules

Roll-to-roll manufacturing with annual production capacity of 15 MW installed by Flisom



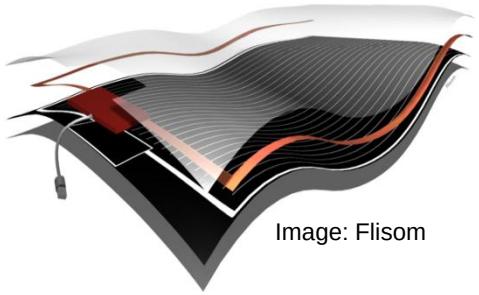
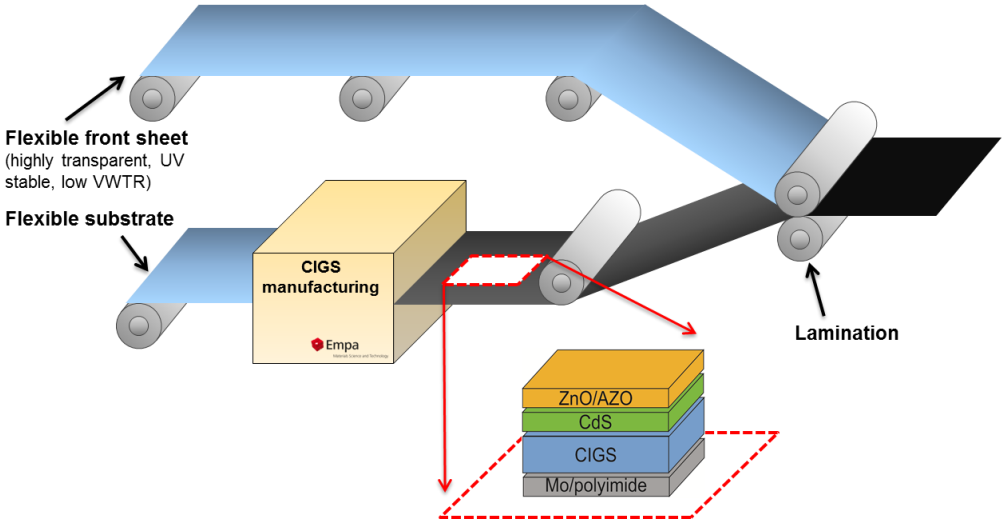
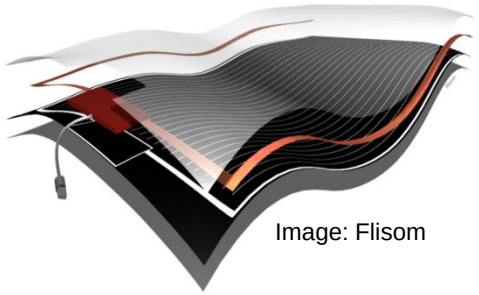


Image: Flisom

Installation of lightweight PV modules from Flisom

Lightweight Thin Film PV Modules





Can we increase the efficiency with **no** or only slight increase of costs/Wp?

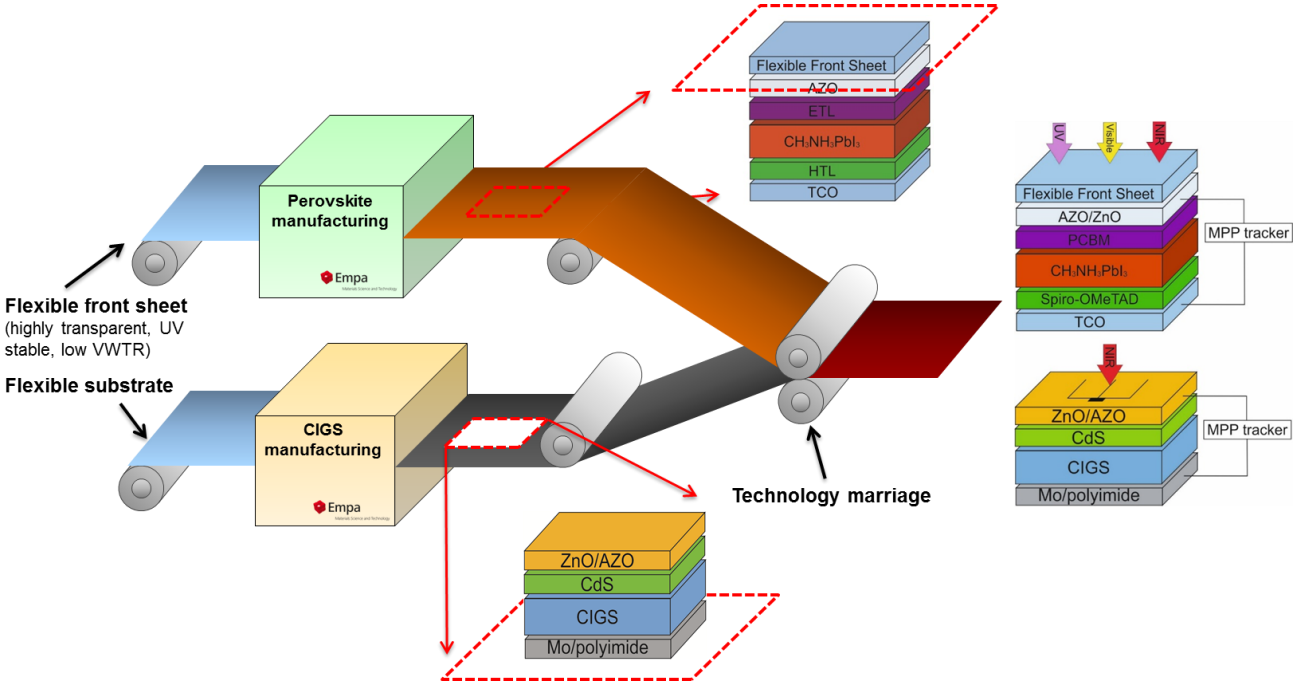
Majority of module costs arise from

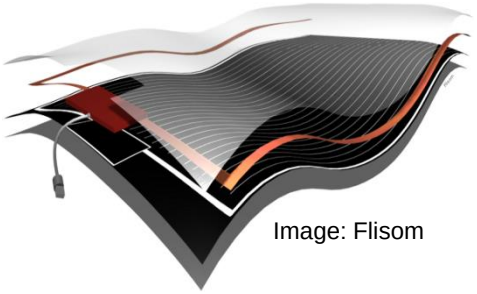
- substrate,
- back side encapsulation,
- front sheet;

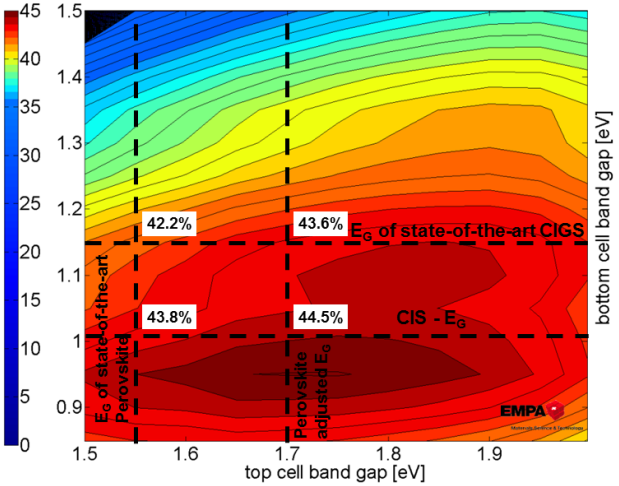
Towards super high efficiency: >30% thin film solar cells

Stacking of solar cells optimized for different parts of the solar spectrum

TANDEM lightweight Thin Film PV Modules





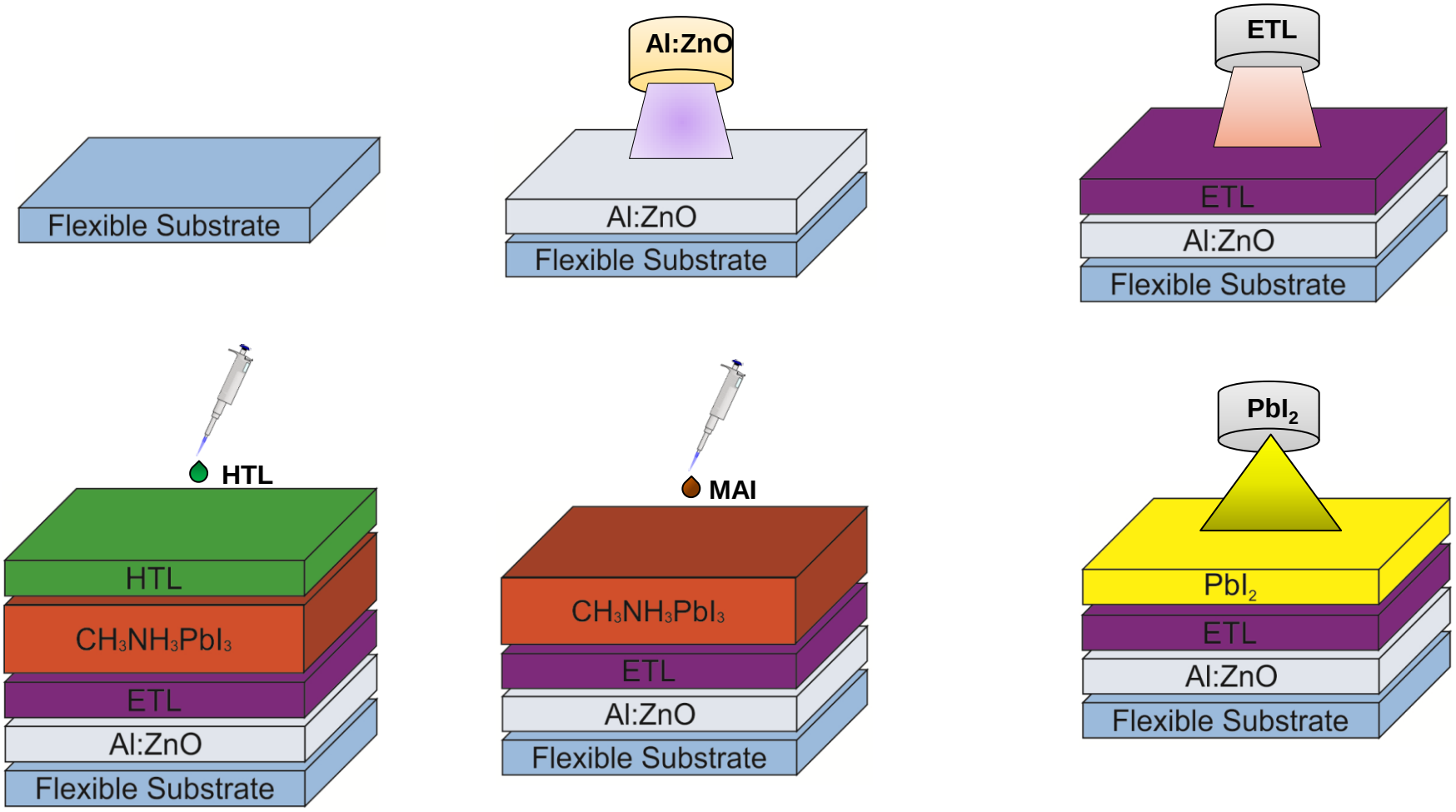


Milestones

- Flexible and NIR transparent perovskite solar cell directly on the front sheet material
- Sufficient stability of the perovskite top cell
- Monolithically interconnection by laser scribing
- Scalable deposition methods
- Substitute costly materials (e.g. HTL)

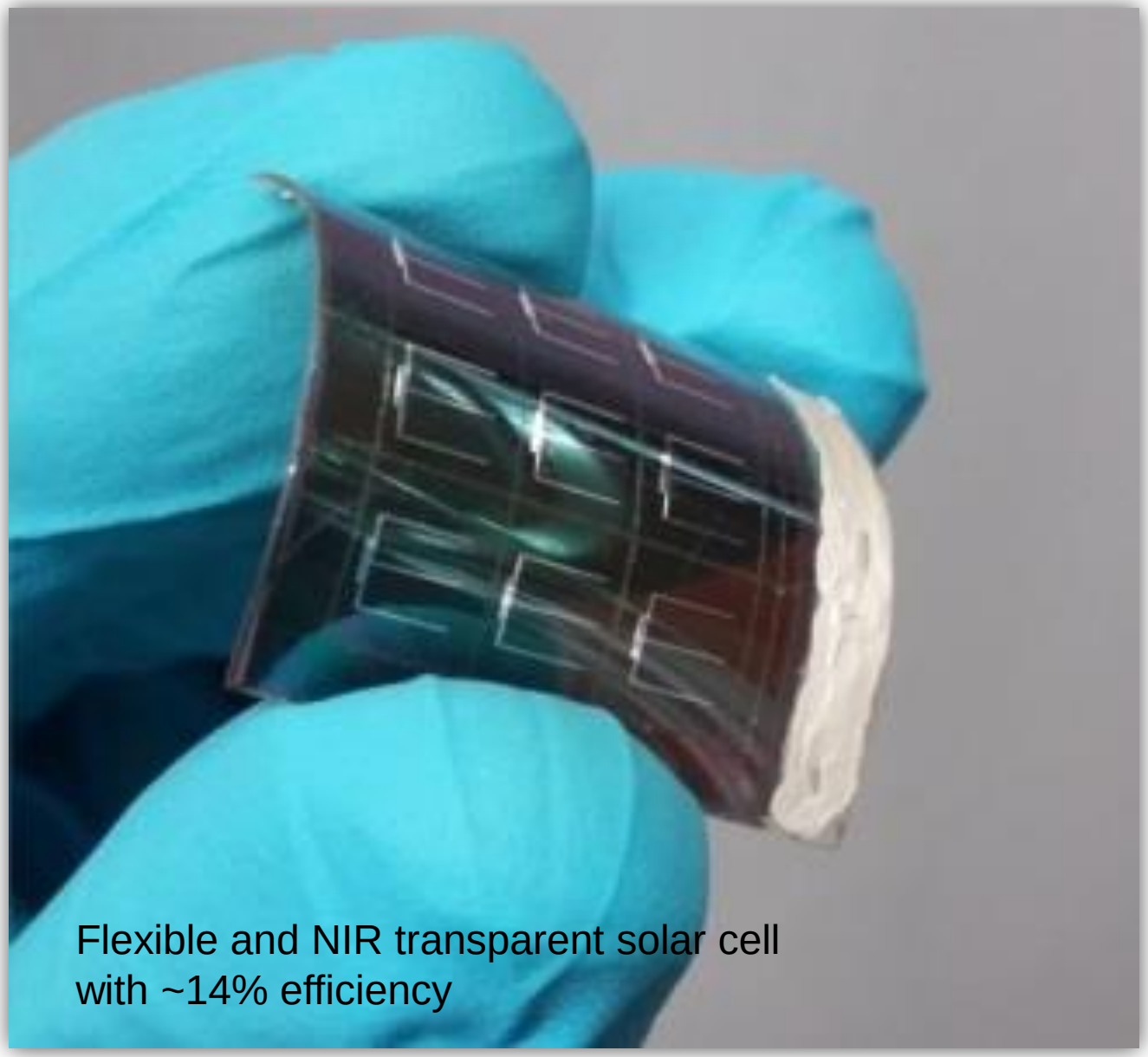
Majority of module costs arise from substrate, back side encapsulation, front sheet;

Flexible Perovskite Solar Cells: Our Device Structure

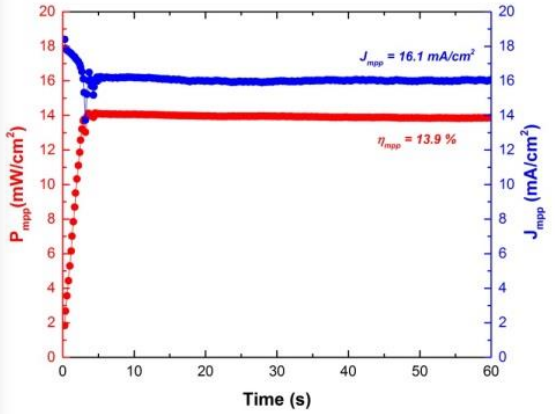


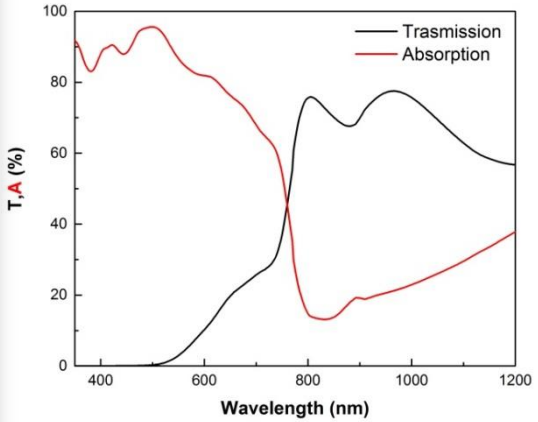
S. Pisoni et al., J. Mater. Chem. A 5, (2017)

NIR-transparent Flexible Perovskite Solar Cells



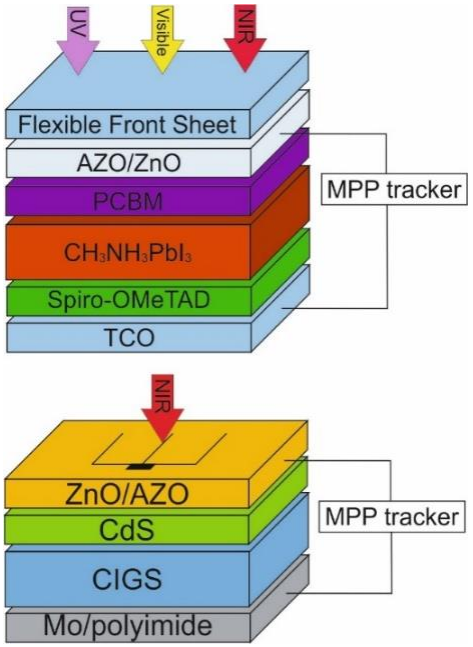
Flexible and NIR transparent solar cell
with ~14% efficiency

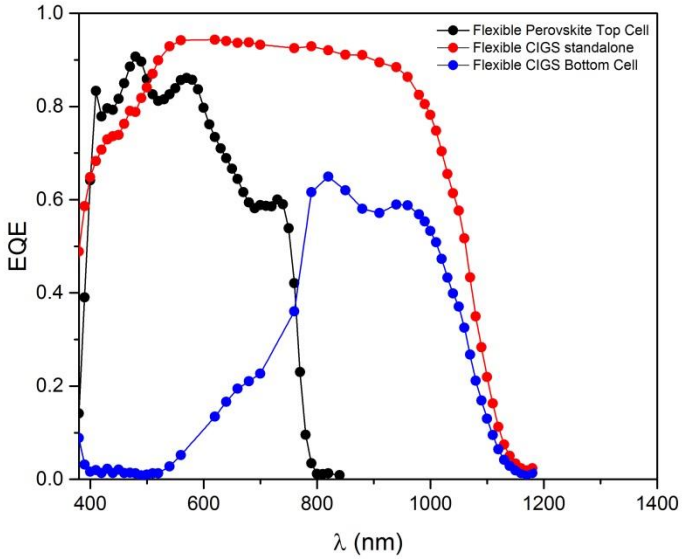




S. Pisoni et al., in preparation

4-Terminal Flexible Tandem Device





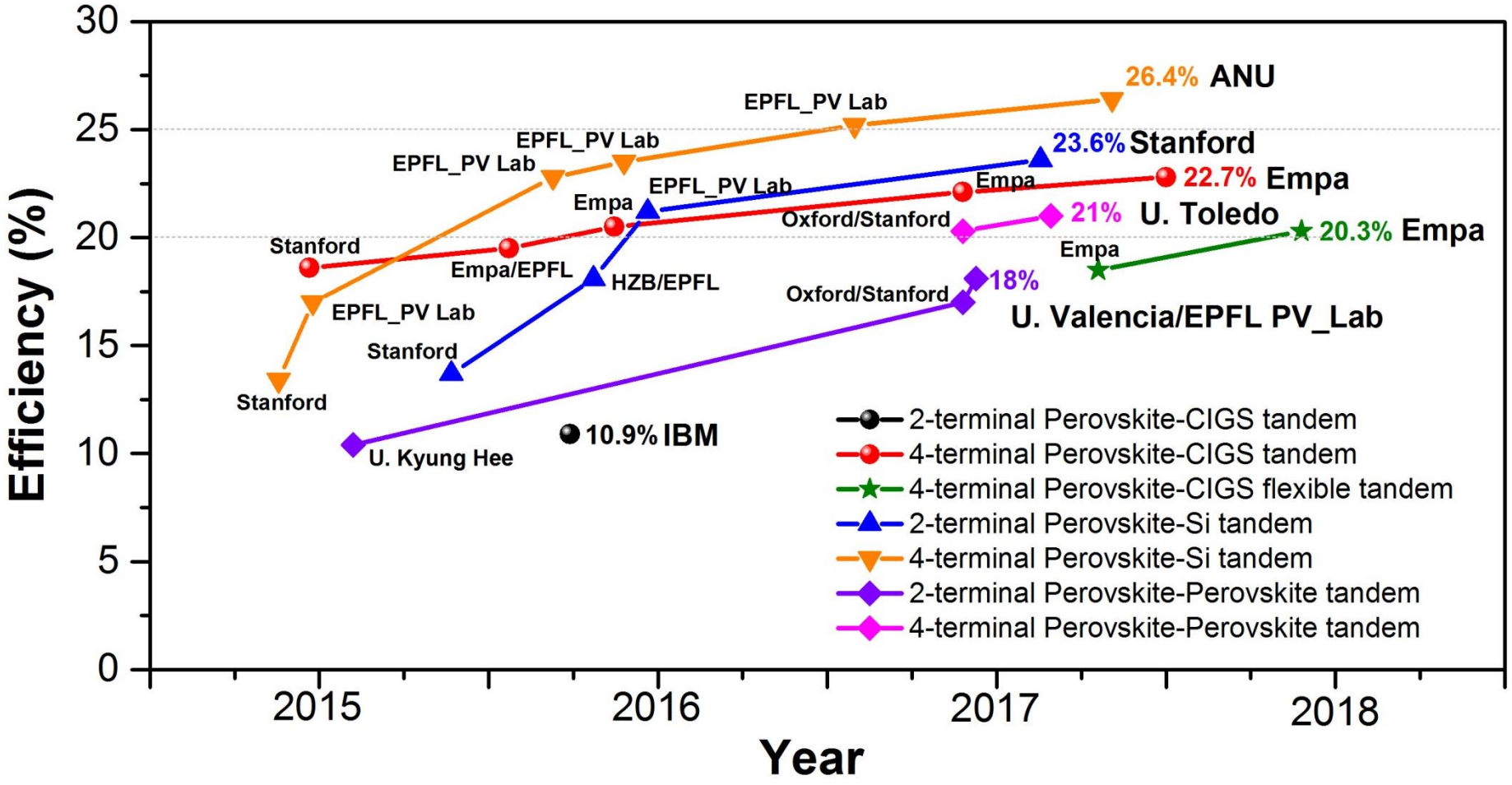
	V_{OC} (V)	J_{SC} (mA/cm²)	FF (%)	η (%)	η_{mpp}(%)	Area (cm²)
Flexible CIGS	0.67	36.3	77.1	18.9	**18.9**	0.213
Flexible CIGS bottom cell	0.64	12.8	77.8	6.4	**6.4**	0.213
Flexible Perovskite top cell	1.08	18.0	70.2	13.7	**13.9**	0.27

→ Corresponds to 203 W/m² if illuminated with 1 sun

Flexible Perovskite/CIGS tandem solar cell with 20.3% efficiency in 4-Terminal configuration

S. Pisoni et al., in preparation

Perovskite-based Tandem Solar Cells



Updated September 2017

Summary and Outlook

- Solar cell efficiencies have crossed 22% bench mark and further efforts are being made towards 25%
- High efficiency flexible and lightweight solar cells are expected to open new application opportunities
- Several untapped market opportunities – especially attractive for buildings, transportation, portable, large-lightweight ground mounts
- New materials, new deposition processes and multi-junctions concepts show potentials for >30% thin film solar cells, but several challenges have to be overcome

sub-cell efficiency – band gap of top and bottom cell – transmission through top cell – recombination layer – NIR response in bottom cell – stability of top cell – scaling the deposition processes – substitute costly materials …

Thank you for your attention

E-MRS
EUROPEAN
MATERIALS RESEARCH SOCIETY

E-MRS Spring Meeting 2018, June 18th-22nd, Strasbourg
Symposium A: Thin Film Chalcogenide Photovoltiac Materials;
includes workshop on kesterite solar cells
organizers: Stephan Buecheler, Daniel Abou-Ras, Negar Naghavi, Woo Kyoung Kim, Alexander Uhl

Empa
Materials Science and Technology

Disclaimer:
The opinions expressed and arguments employed herein do not necessarily reflect the official views of the Swiss Government or the European Agency