TNO S2S infrastructure for upscaling perovskite solar cells

VIPERLAB Webinar 13-11-2023

Dr. V. Zardetto |

About TNO

Netherlands Organization for Applied Scientific Research

- Independent research organization connecting people and knowledge to create innovations that boost competitive strenght of industry and well-being of society

TNO Energy & Materials Transition Unit

- TNO develops technologies and concepts that drastically reduce the costs of generating **renewable electricity from the sun** and the wind and increase the yield

15 locations

PV Perovskite activities in TNO

- Facilities proposed in VIPERLAB located in Eindhoven

15 locations

TNO partner in Solliance

Solliance public R&D partners

TNO · imec · JÜLICH FORSCHUNGSZENTRUM · TU/e · UHASSELT · TU Delft · UNIVERSITY OF TWENTE. · university of groningen

Collaboration with industry partners

Materials · *Equipment* · *PV Producers* · *End-users*

Heraeus · posco · VDL · MAAN · Panasonic · MiaSolé · FleXipol · Shell · nano-c · greatcellsolar MATERIALS · MEYER BURGER · SMIT THERMAL SOLUTIONS · solartek · SEKISUI · heijmans · KNAUF · Scheuten see it. feel it · TATA STEEL · Rexroth Bosch Group · eternal sun · Heliatek · AVANCIS · BMI MONIER · solarge · DSM · POWER ROLL · SoLayTec · merphotonics · thyssenkrupp · HyET Solar · POLYPLASTIC · ptt · endurans solar · covestro · SINGULUS · Meco · Hanergy · ad pv · nTact · SIOUX · Disa Solar · greatcellenergy · D&M · TOE TROLLER · MITSUBISHI CHEMICAL · Qcells

Partners in Research and Industry: Past and Current

Scalable process routes

- Solution processing
- Atmospheric pressure spatial ALD
- Sputter processing
- Laser processing
- Encapsulation

TNO Scaling up perovskite technology

- Sputtering

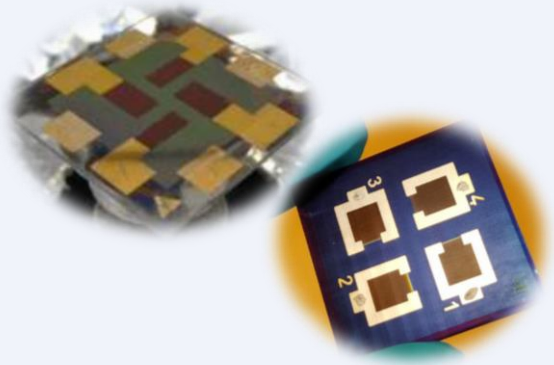
- sALD

- Slot die coating

- Evaporation

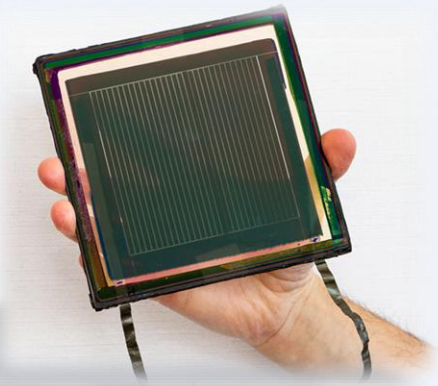
- Laser scribing

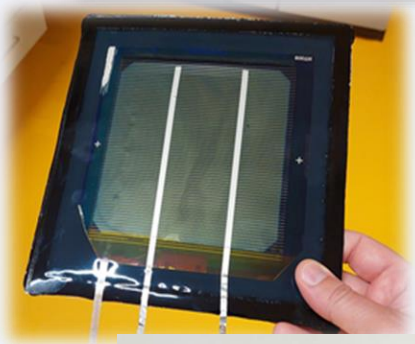
- Encapsulation

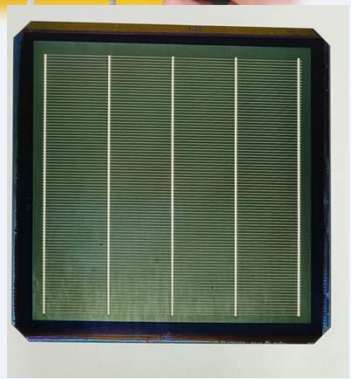


0.09 to 1 cm^2

- **Industrially relevant deposition methods**
- Proof of concept at intermediate area
- Ambient and/or protected atmosphere
- Evaluate risks and mitigations

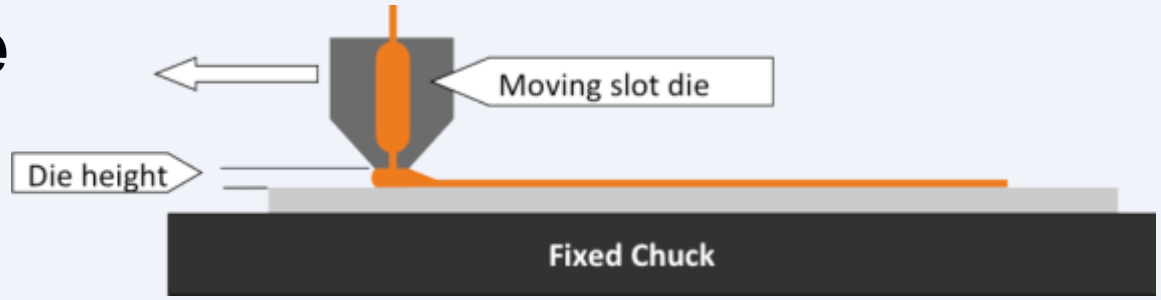






> 100 cm^2

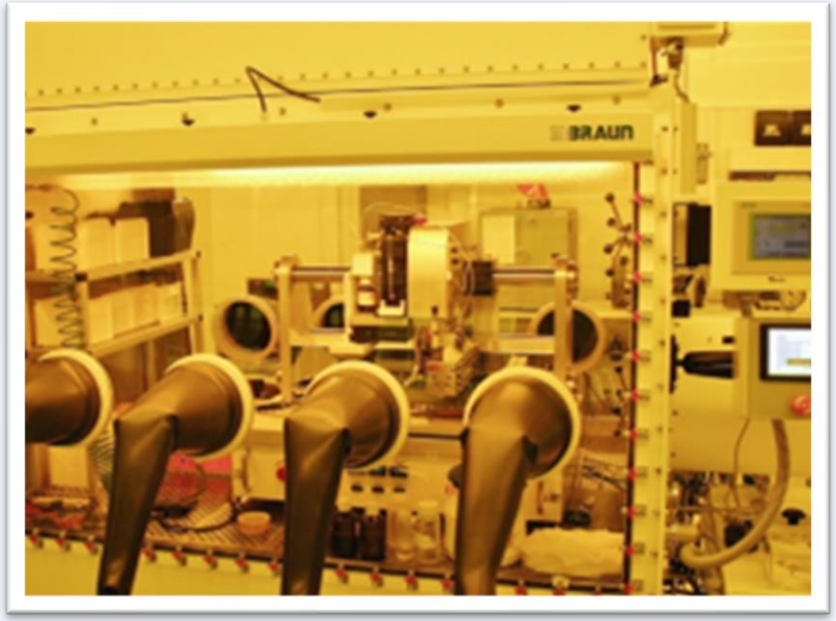
Solution processing: slot die



- SD allows for uniform coating on large area
- Compatible with sheet-to-sheet and roll-to-roll
- Allows for simple patterning (stripes / squares)

- Deposition of transport layers

- For perovskite challenges lie in the drying/annealing step (crystallization)
  - Process control - Vacuum quenching (3° g. S2S)
  - Ink compatible with ambient processing (S2S and R2R)
  - *Coming up gas quenching process*



Available infrastructures

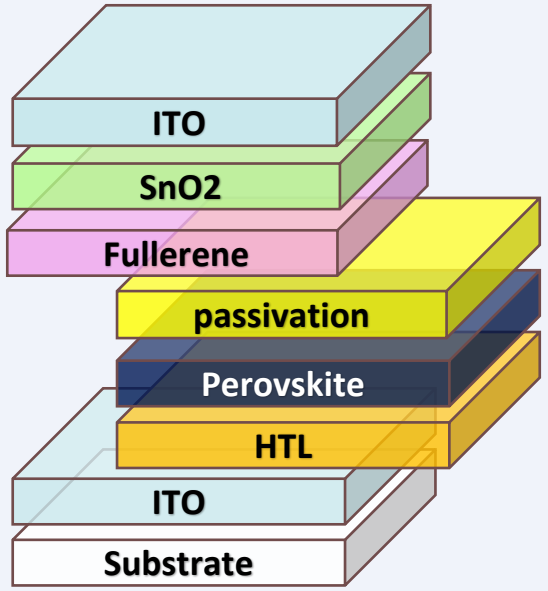
Slot die coater up to 15.2 cm x 15.2 cm in inert atmosphere I n combination with **vacuum quenching chamber**

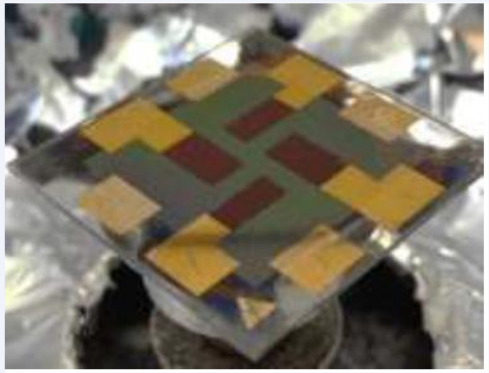
Slot die coater up to 30 cm x 40 cm in ambient atmosphere in combination with **vacuum quenching chamber**

Slot die coater up to 32 cm (width) x meters in ambient atmosphere with closed furnaces with driers of 20 m and 15 m long

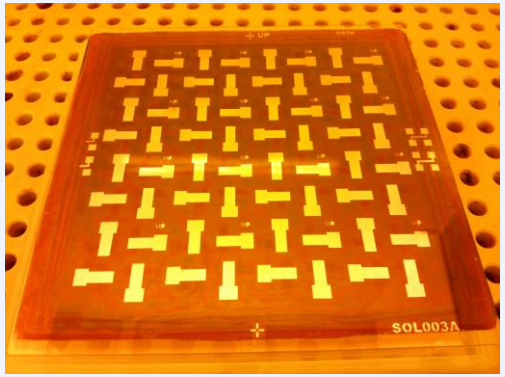
(N.B. not in VIPERLAB)

Perovskite TNO Baseline





Spin coating
+ gas quenching

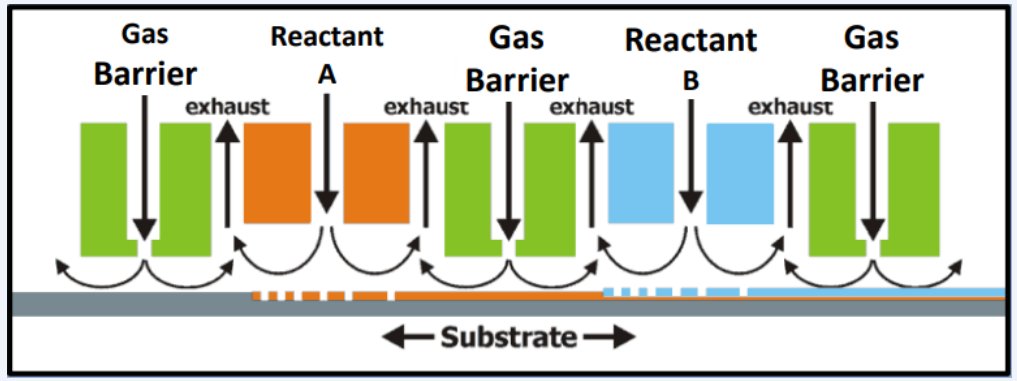


Slot die coating
+ vacuum quenching

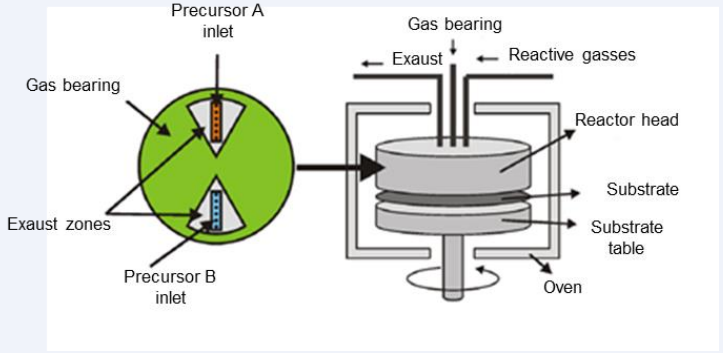
ST-PSC type	Area (cm^2)	J_{SC} (mA cm^{-2})	V_{OC} (V)	FF (%)	PCE (%)	MPPT (%)
Spin coating – best cell	0.09	21.6	1.128	79.8	19.5	**19.6**
Slot die coating – best cell	0.09	22.7	1.122	77.9	19.9	**19.9**

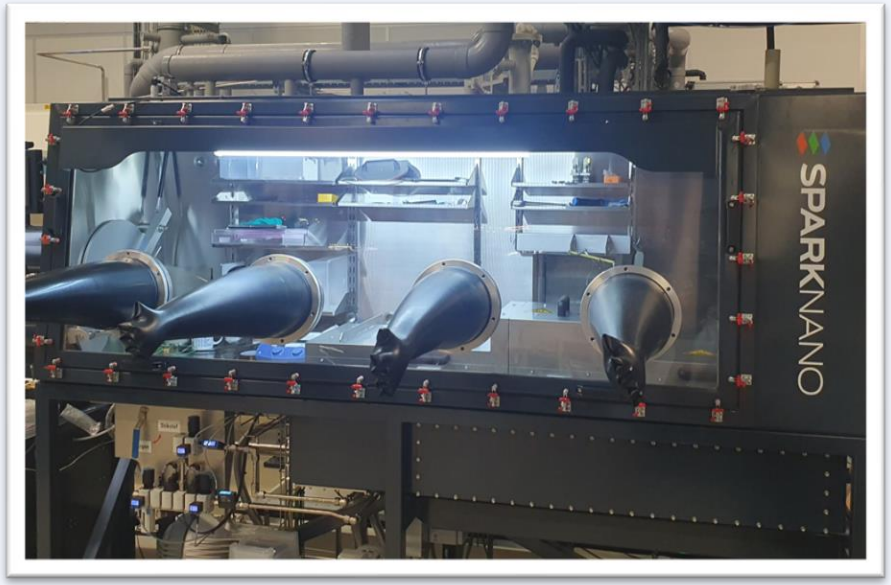
Spatial ALD

- Atmospheric pressure spatial ALD to deposit dense, pinhole free metal oxides films used as transport and buffer layers
- SnO_2, ZnO, TiO_2, Al_2O_3, HfO_2, MgO, etc…



Lab scale reactor

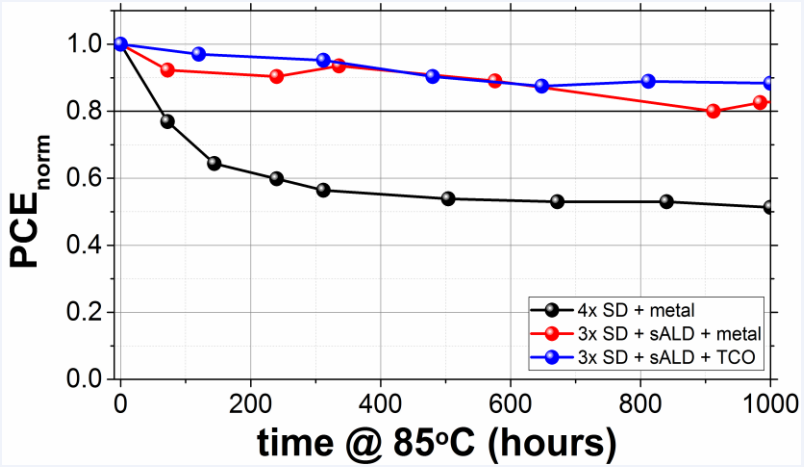


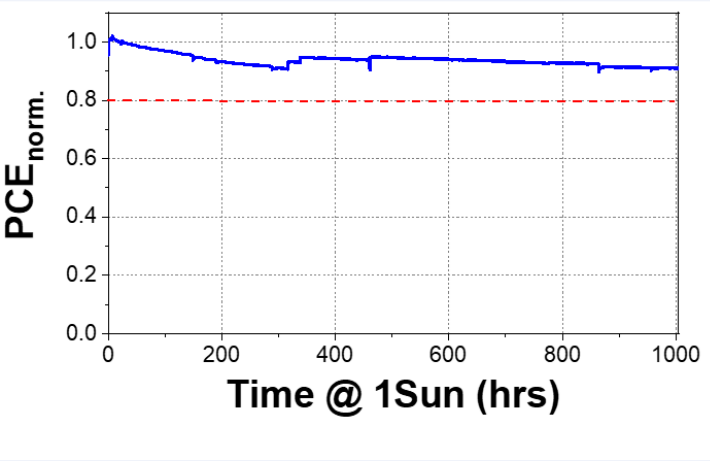


Spatial ALD: SnO_2

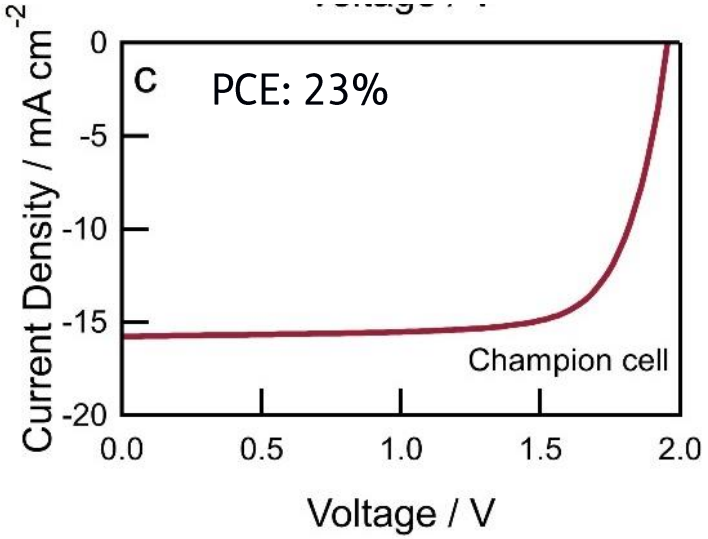
- sALD layer has positive effect on the long term stability of the device architecture

- Highly dense SnO_2 is required for solution process tandem and multi junction perovskite devices

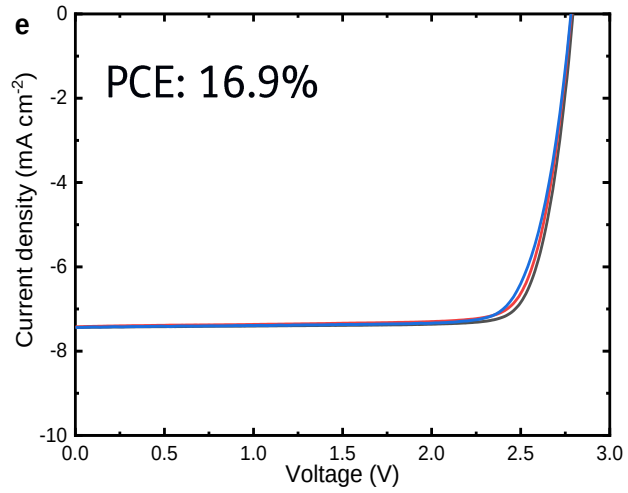




Zardetto et al., 7th WCPEC 2018, 3514-3517



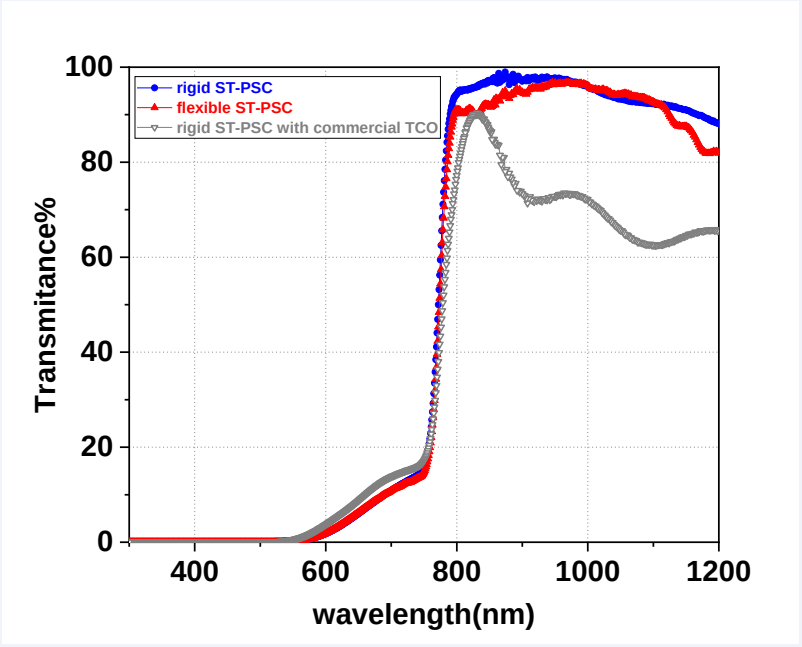
Datta et al., Advanced Materials 34 (11), 2110053

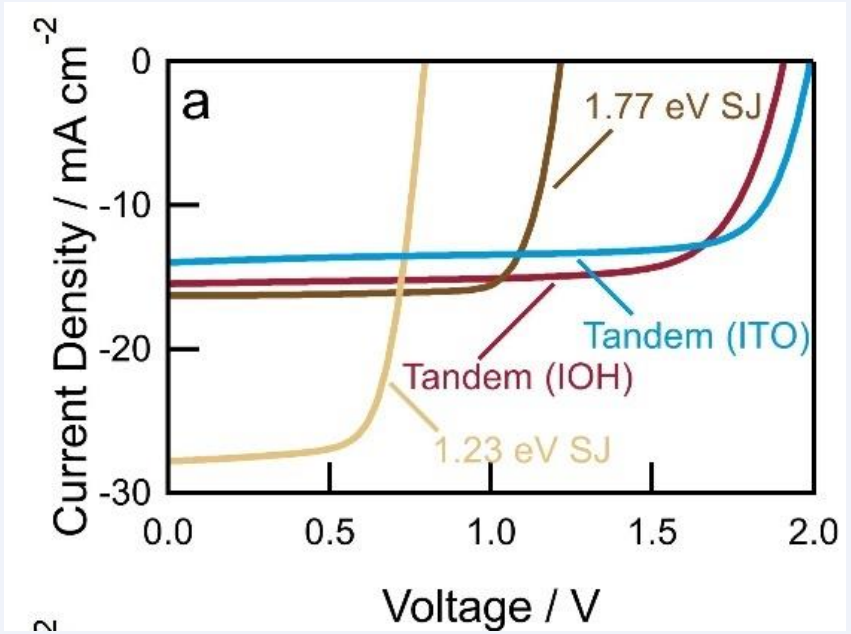


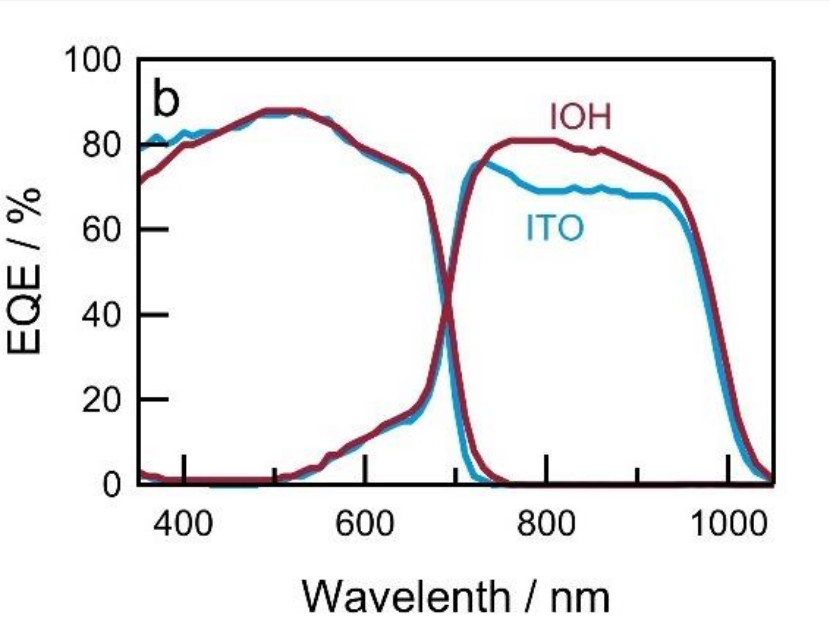
Wang et al., Nature Communications 11 (1), 5254

Sputtering processes

- Improving TCO near infrared transmittance (700 - 1200 nm) for tandem applications
  - ITO
  - InOH







Datta et al., Advanced Materials 34 (11), 2110053

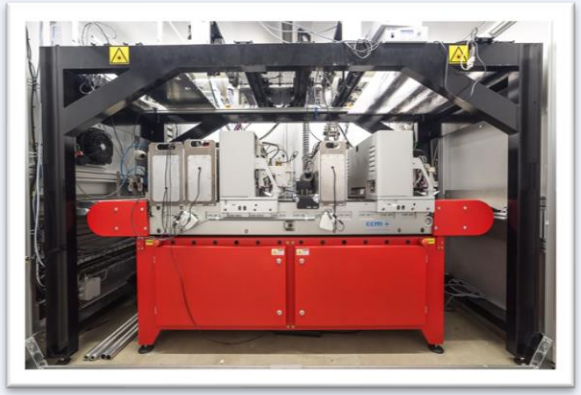
Laser processing

Wavelengths: 355, 532, 1064 nm

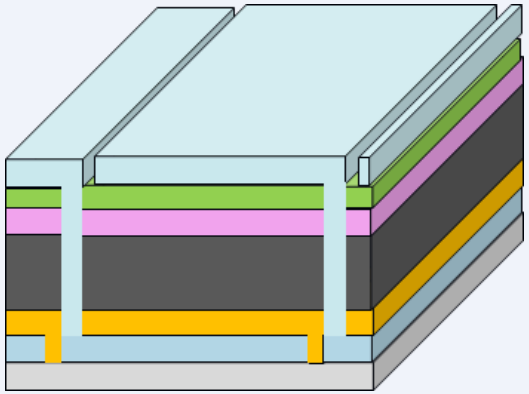
Pulses: ns, ps, fs

Powers: 0.8-10W

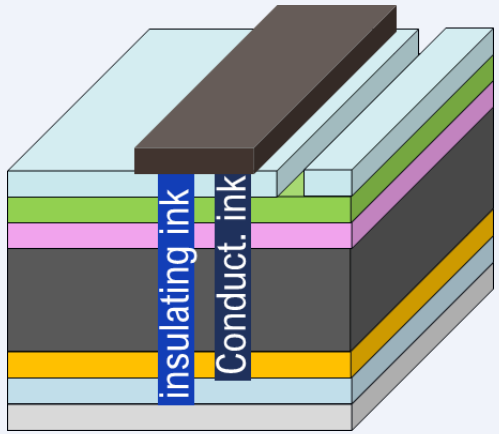
Area: up to 30 cm x 30 cm



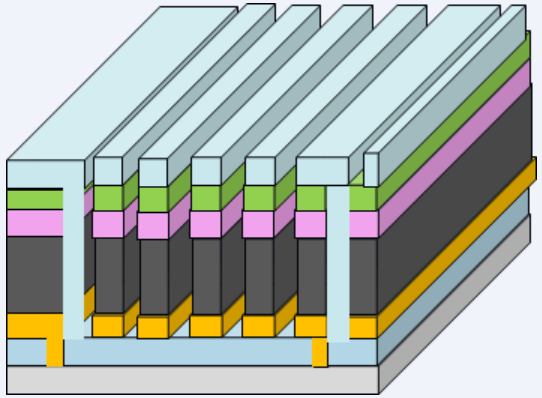
Conventional P1,P2,P3

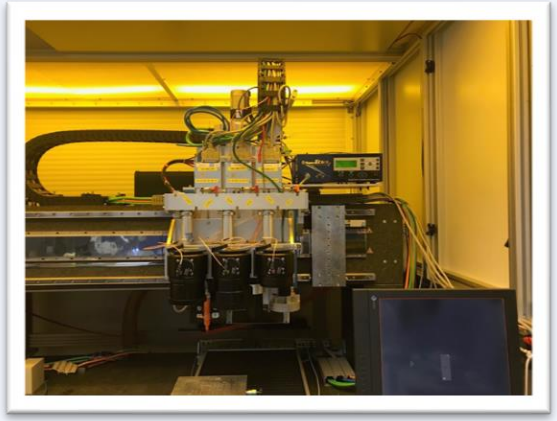


Back end processing

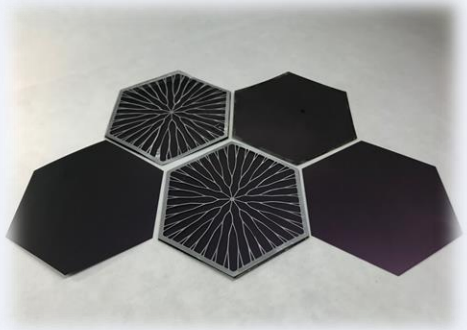


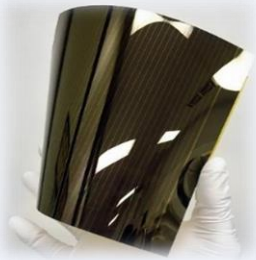
Translucency

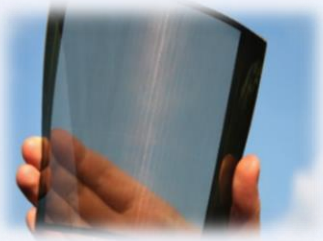




Semitransparent perovskite stack

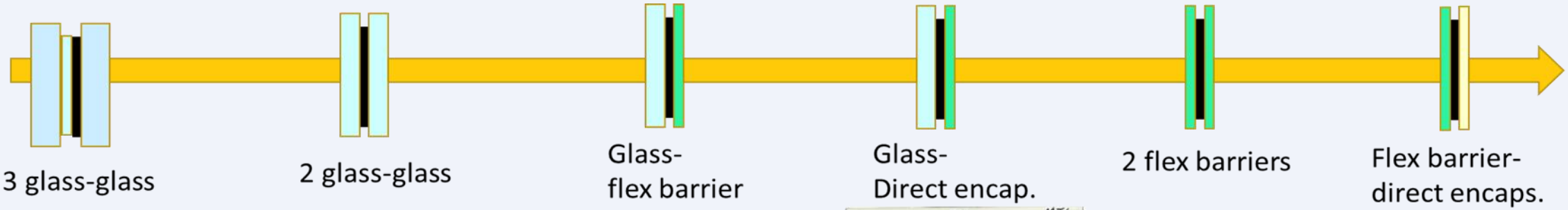






Encapsulation & Stability

Damp-heat test stability is achieved using several encapsulation strategies



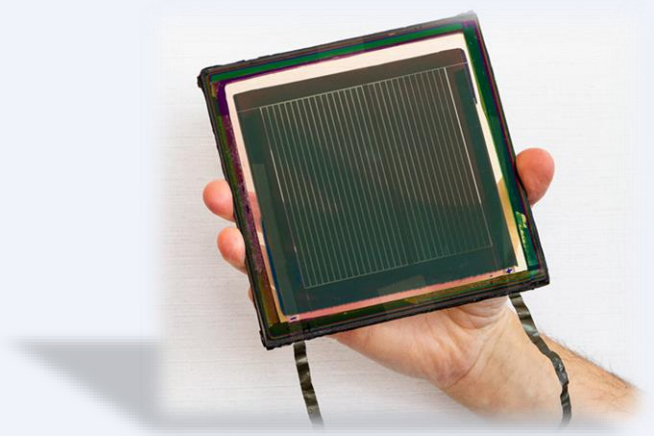
Perovskite based large area devices

- Single junction modules
- Stability
- Tandem devices

Module Manufacturing & Interconnection

S2S processed rigid perovskite module

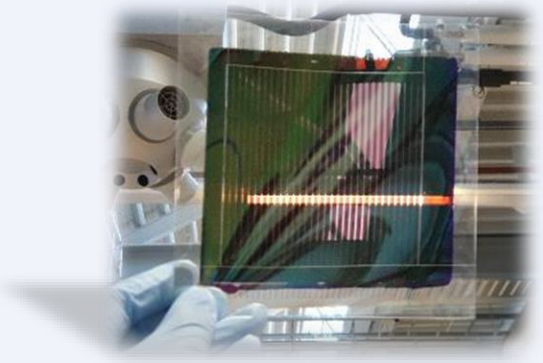
- Module aperture area: 10x10 cm^2
- Geometric fill factor: >92%
- Bifaciality factor: >90%



Type		I_{sc} (A)	V_{oc} (V)	FF (%)	PCE (%)
ST- Module	REV	0.063	35.5	70.5	16.0
	FORW	0.063	35.2	70.9	16.0
	MPPT				**16.0**

S2S processed flex perovskite module

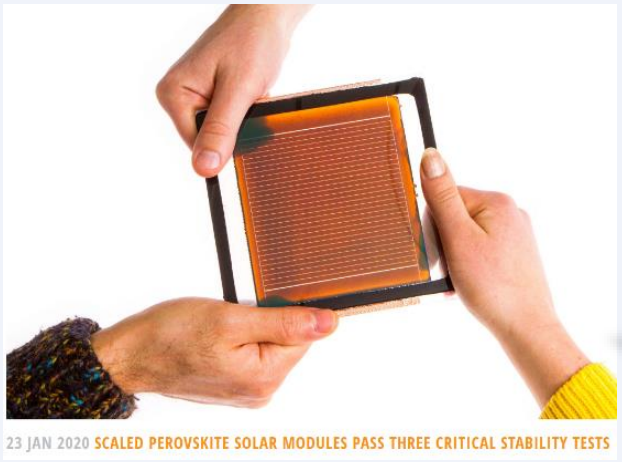
- Module aperture area: 10x10 cm^2
- Geometric fill factor: >92%
- Bifaciality factor: 97%



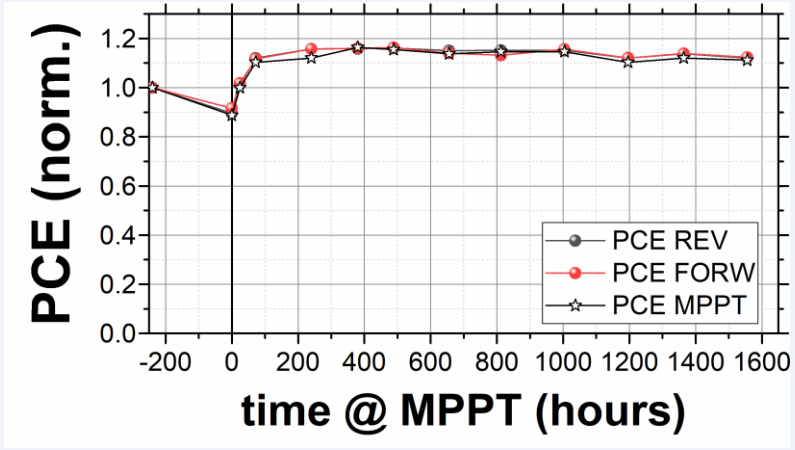
Type		I_{sc} (A)	V_{oc} (V)	FF (%)	PCE (%)
NT-Module (white BR)	REV	0.061	34.1	62.9	13.1
	FORW	0.061	34.0	62.6	12.9
	MPPT				

Module Reliability

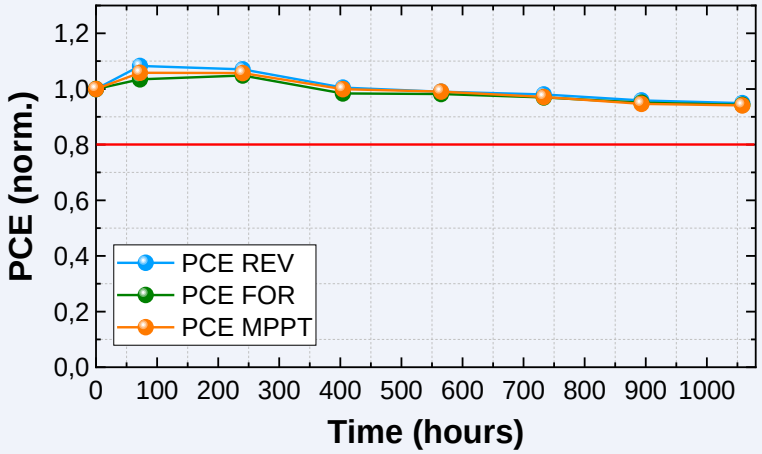
Press release



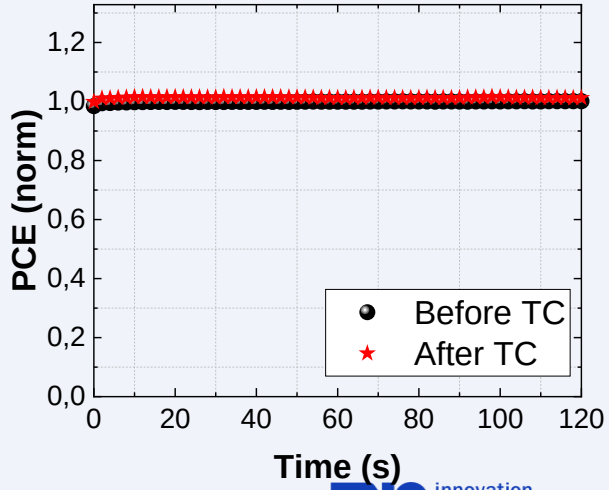
>1000 hr Light soaking test with no loss



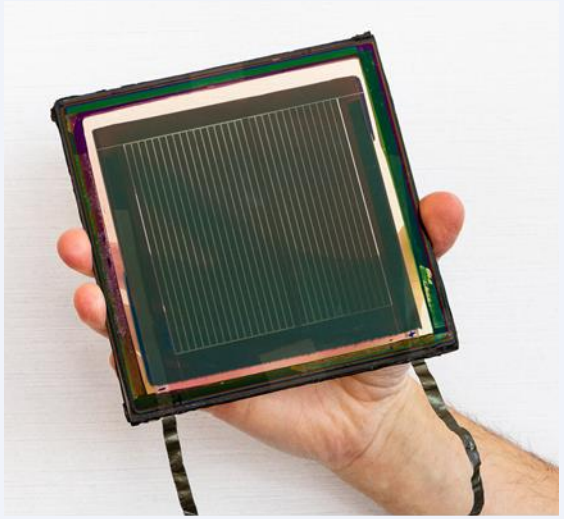
1000 hr D/H test with 92% of initial PCE



200 cycles of TC test with 98% of initial PCE



Example large area devices 4T



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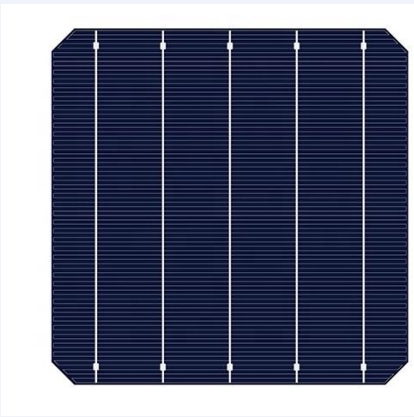

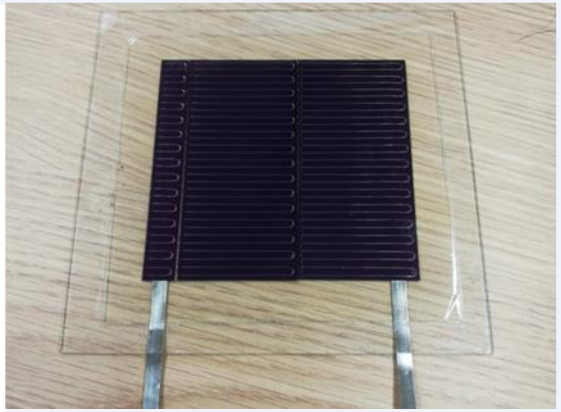

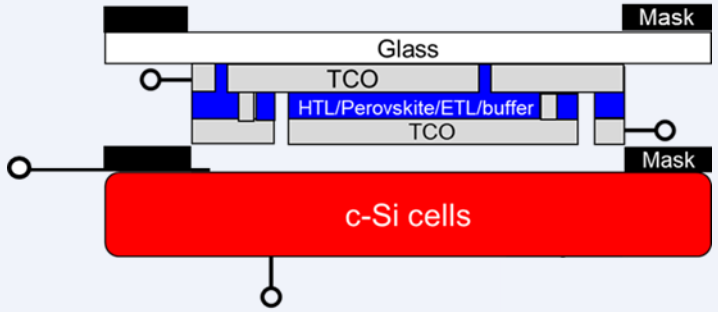

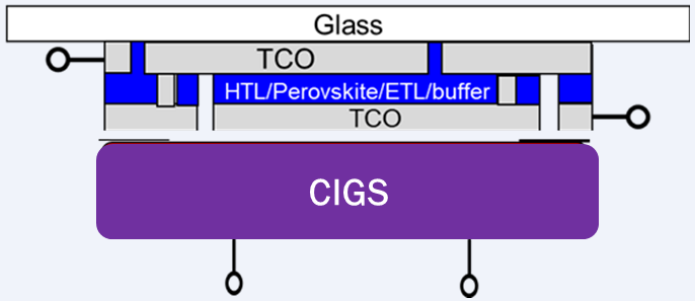

Type		I_{sc} (A)	V_{oc} (V)	FF (%)	PCE (%)
ST-Module (1.6eV) (100cm²)	REV	0.063	35.5	70.5	15.98
	FORW	0.063	35.2	70.9	15.94
	MPPT				**16.05**
SHJ (1.1eV) (Masked 100cm²)	SJ	3.93	0.717	78.8	**22.21**
	Bottom	1.73	0.704	78.8	9.59
4 TANDEM					**25.64**
Flex CIGS (1.2eV) (84.8cm²)	SJ	1.350	1.48	74.3	**17.56**
	Bottom	0.479	1.40	75.0	5.93
4 TANDEM					**21.98**

Thanks for your attention

Giulia Lucarelli
Marcel Simor
Hero Mannetje
Manvika Singh
Mehrdad Najafi
Bart Geerligs
Yu Wu
Aravind Srinivasachari
Petra Manshanden
Victor Rosca
Arthur Weeber
Veronique Gevaerts
Sjoerd Veenstra
Gianluca Coletti
Ilker Dogan
Harrie Gorter
Anuja Vijayan
Dorrit Roosen-Melsen
Wiljan Verhees
Henri Fledderus
Anne Biezemans
Klaas Bakker
Monique van den Nieuwenhof
Niels van Loon
Marc Koetse
Peter Toonssen
Carlijn Vernooij
Jan Hoegee