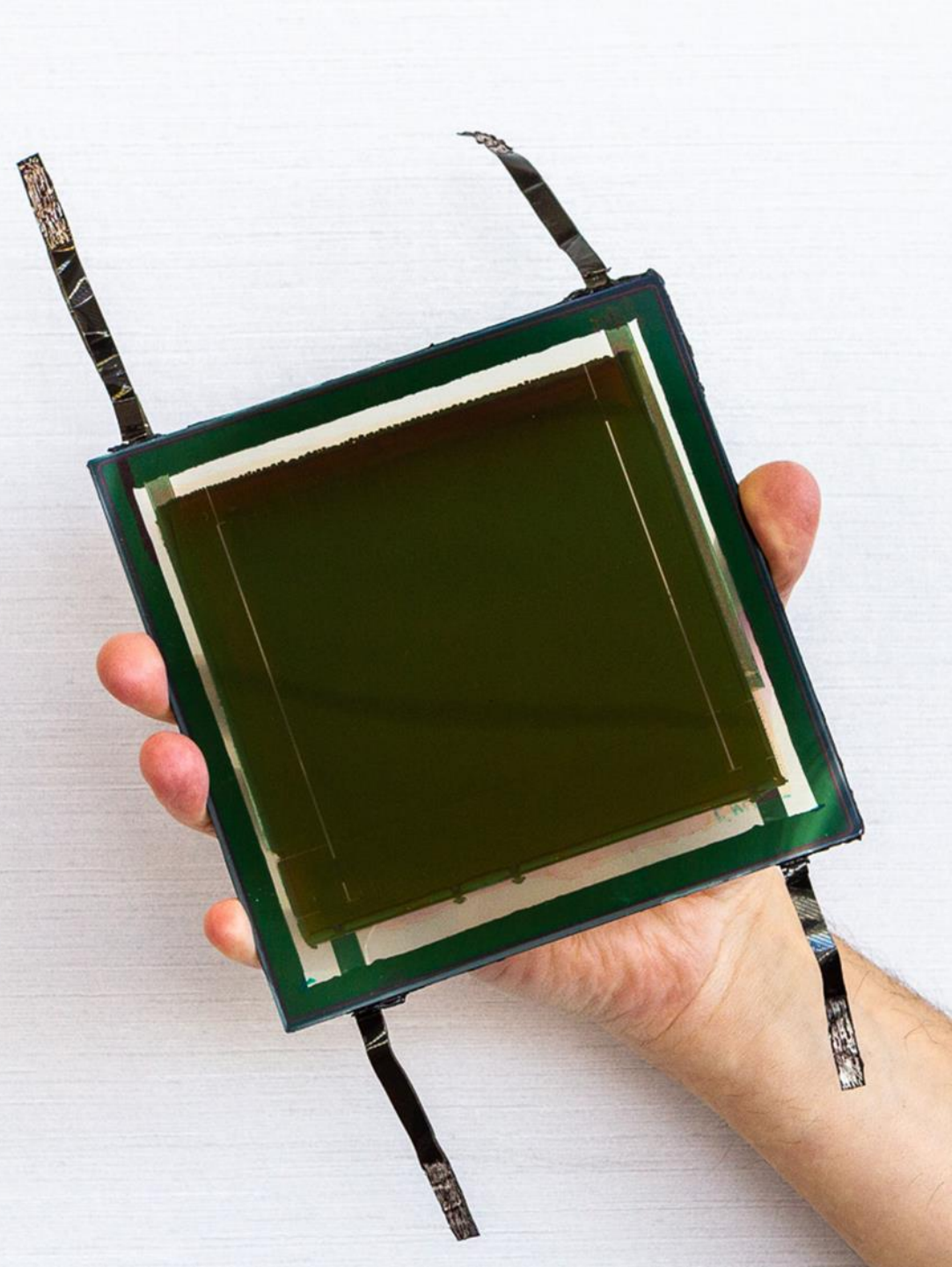
High Efficient Perovskite and Hybrid Tandem Devices

From lab scale to large area deposition methods

Dr. V. Zardetto |

TNO innovation for life

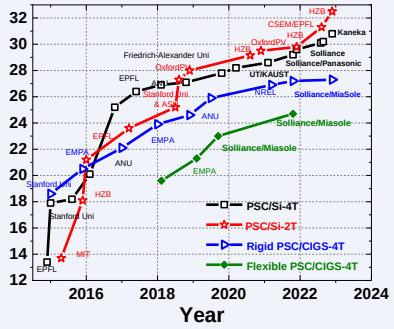


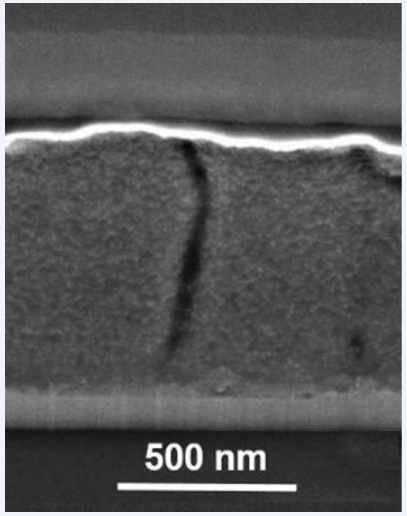
Outline

- TNO approach
- Small area perovskite single junction and hybrid tandem
- Moving to large area deposition methods
- Example of large area 4T and 2T tandem devices

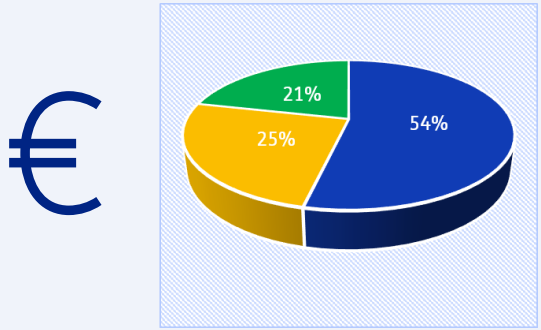
TNO approach

Performance



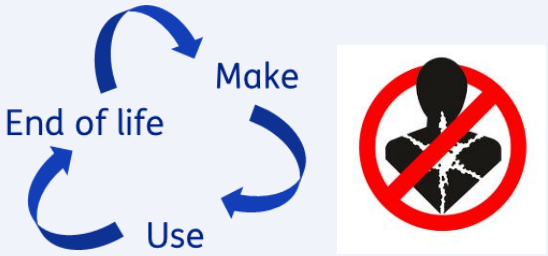


Costs



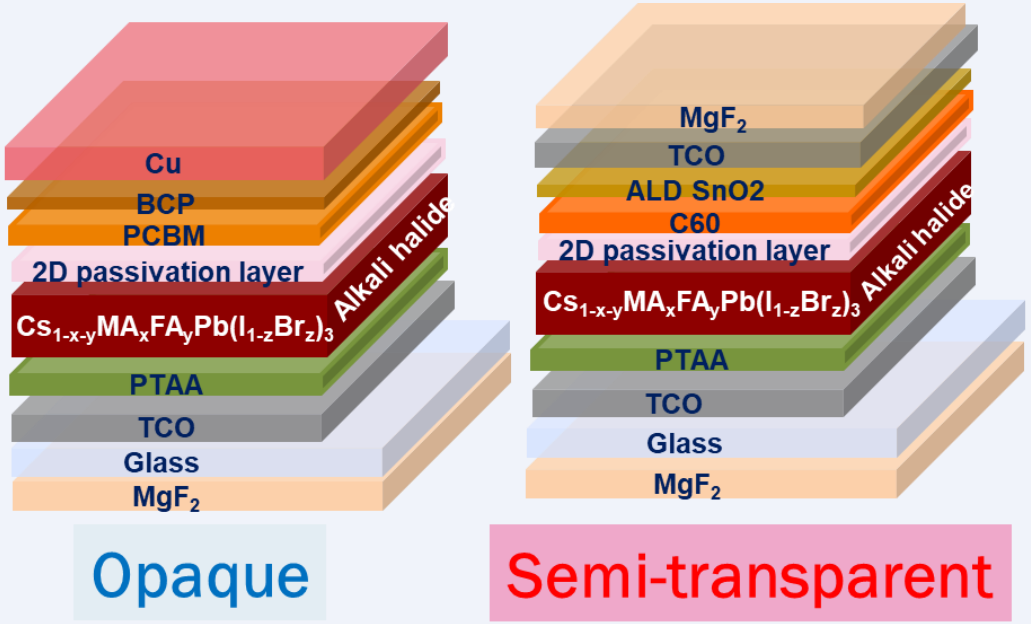
Stability

Sustainability & recycling



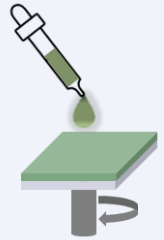
Scalability

Lab scale efficient perovskite solar cells



Cell type	Description	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	PCE (%)
Opaque PSC (1.6eV)	Backward scan	1167	22.4	83.0	21.8
	Forward scan	1164	22.4	82.0	21.3
	10 min MPPT	-	-	-	**21.9**
ST-PSC (1.6eV)	Backward scan	1154	22.2	80.0	20.5
	Forward scan	1152	22.1	78.5	20.0
	5 min MPPT	-	-	-	**20.6**

Lab scale efficient perovskite solar cells



ESTI — European Solar Test Installation

Record | Code: E31 | Index: t

PV Device Performance Sheet

Manufacturer	TNO	Serial Number	2022-7-20 S4-cell4
Module Type	Cell	Esti Code	XF812
Module ID		Test Sequence	PS

Mask area [mm²]	9.01	Cells in parallel	1	Cell Structure	
Module area [m²]	0.00	Cell in series	1	PSK	

Reference Detector	PX502A	Light Source	Wacom	CSS
Multiflash measurement	Y			

	Isc [mA]	Voc [V]	Imp [mA]	Vmp [V]	Pmax [mW]	FF [%]	Cell_Eff [%]	Mod_Eff [%]
Electrical Performance Data								
Measurement 1	1.977	1.139	1.838	0.963	1.77	78.59	19.6	
Measurement 2	---	---	---	---	---	---	---	---
Measurement 3	---	---	---	---	---	---	---	---
Result	1.977	1.139	1.838	0.963	1.770	78.59	19.64	---
Standard dev.	---	---	---	---	---	---	---	---

Additional Data

	Tref	Tdut	Date	Time	File name
Meas 1	25.0	24.6	05/08/2022	15:00	XF812_Manual_IV_final.stf
Meas 2	---	---	---	---	---
Meas 3	---	---	---	---	---

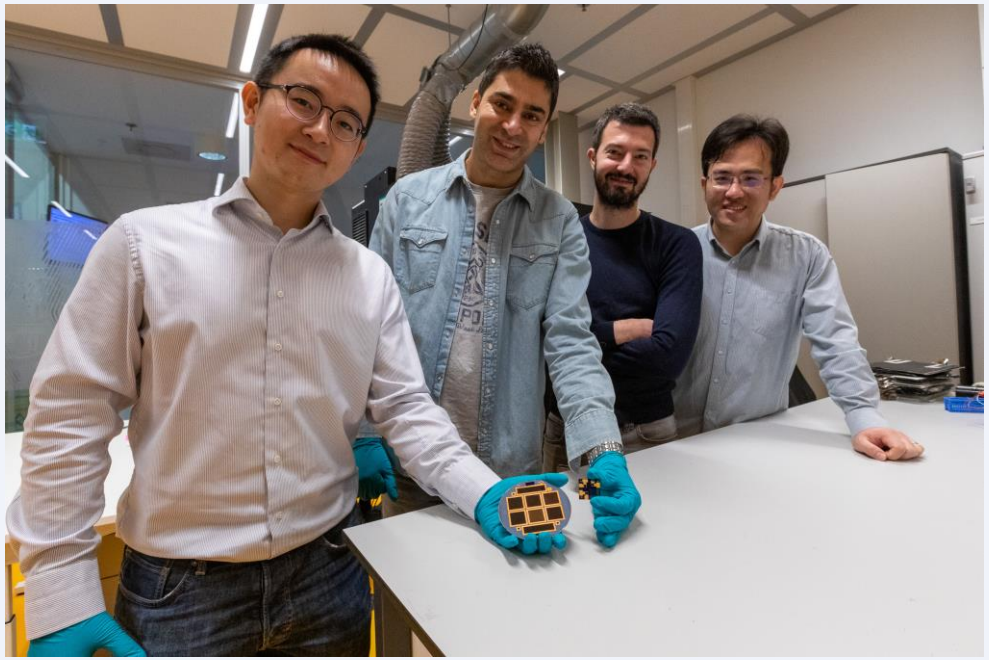
Spectral Responsivity Fiche nr. [E33]	2435	---	---
Mismatch	1.0028	---	---
---	---	---	---
---	---	---	---
	---		---

Final Values corrected to STC
1000 Wm^{-2}, 25 °C and AM1.5 Global

				k=2 [%]
Isc	1.983	± 0.032	[mA]	± 1.6
Voc	1.1394	± 0.0014	[V]	± 0.12
Pmax	1.776	± 0.030	[mW]	± 1.7

Remarks:
Tdut: average temperature of the device during the whole measurement.
Only one meas. perf. with Manual IV proc. Efficiency@STC (19.7±1.9)%

Fiche No.	Performance Executed		
	Date	Name	Signature
3548	5-Aug-2022	B. Mihaylov	



TU Delft

TNO

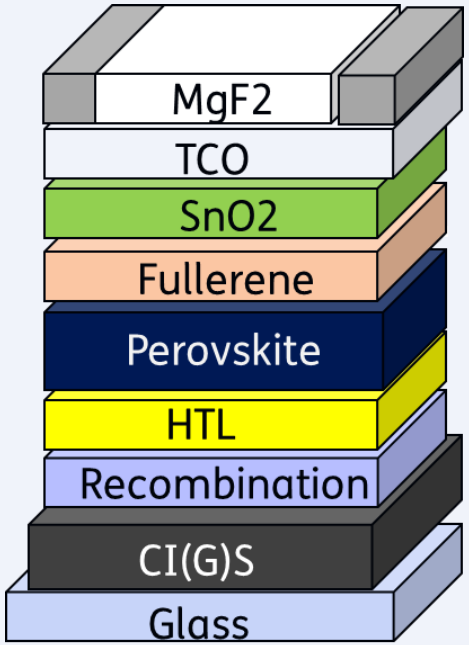
TU/e

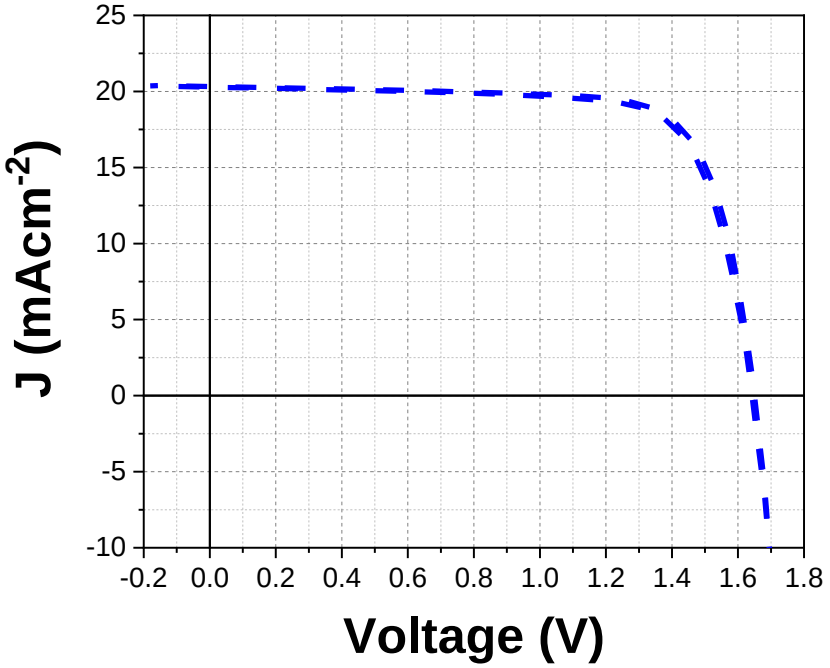
imec

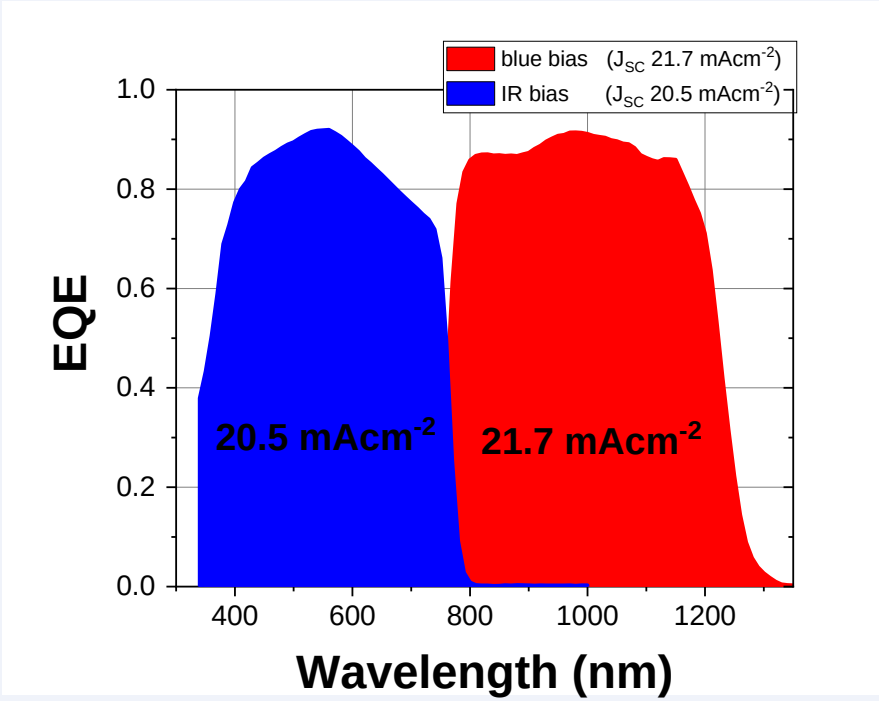
SOLLIANCE

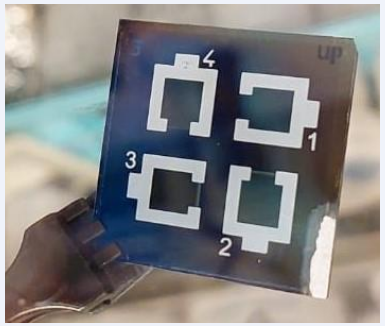
Cell type	Description	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	PCE (%)
Perovskite cell Measured at ISPRA	Top cell	1139	22.0	78.6	19.7
TU Delft SHJ (M16884)	Filtered	711	17.8	82.0	10.4
4T Tandem	-	-	-	-	**30.1**

Lab scale efficient hybrid tandem solar cells









Scan	J_{SC} (mAcm^{-2})	V_{OC} (mV)	FF (%)	PCE (%)	MPPT (%)
RV	20.3	1650	75.9	**25.42**	**24.6**
FW	20.3	1642	75.2	**25.08**	

Scaling up perovskite technology

Industrial relevant deposition processing

- Sputter

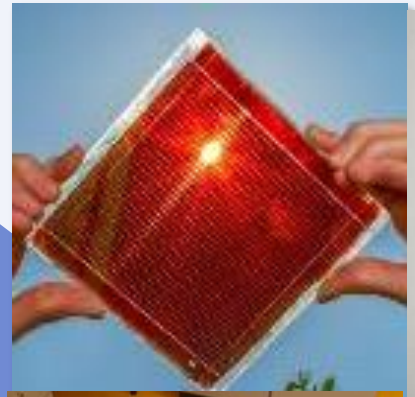
- Evaporation

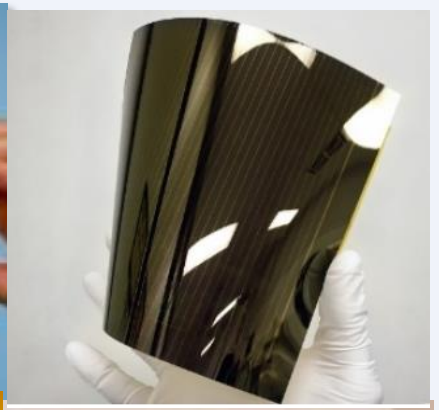
- Slot die

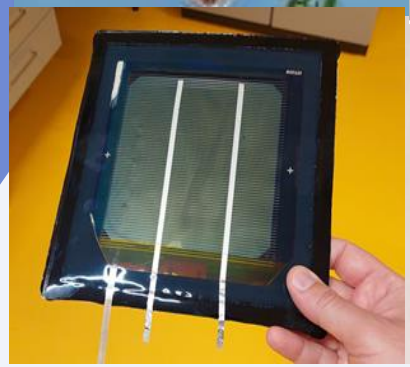
- sALD

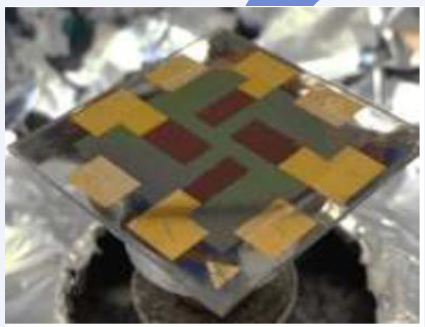
- Laser

- Encapsulation







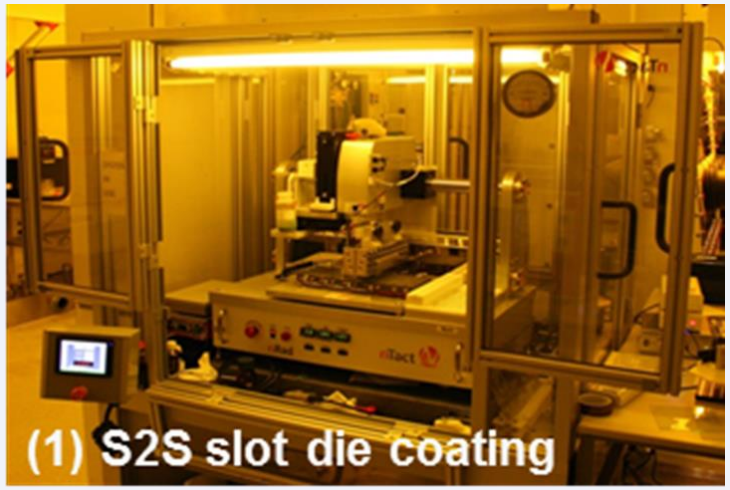


- Proof of concept at intermediate area
- Transfer of the recipe
- Ambient and/or protected atmosphere
- Evaluate risks and mitigations
- Process optimization

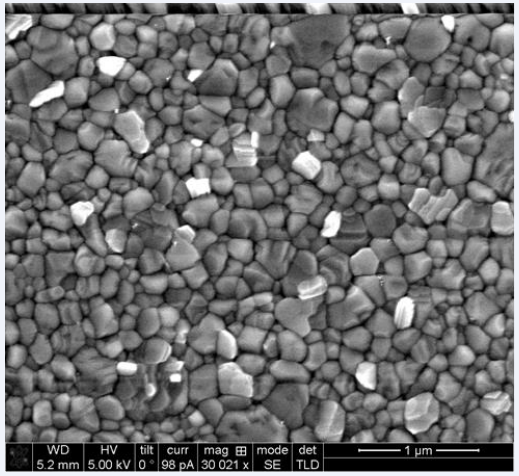
>100 cm^2

From spin coating to slot die coating

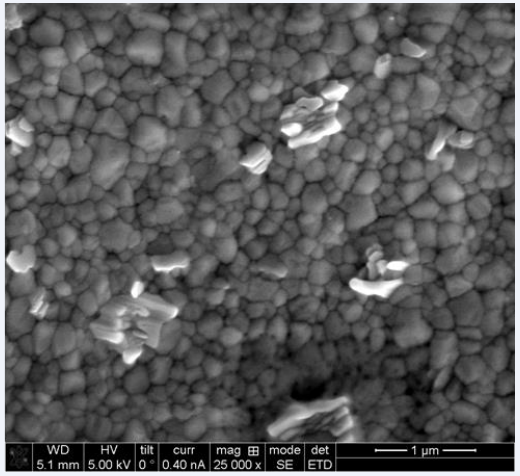
- Ink engineering: stoichiometry, solvent system, additives
- Quenching crystalization processes: gas, vacuum, thermal over 6” or 12”
- Glass, PET, Metals, bottom cells as substrates



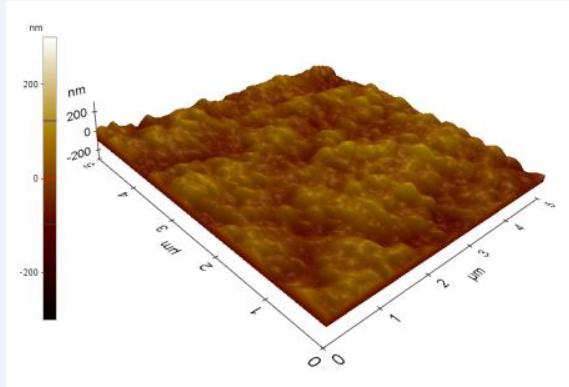
Spin coating



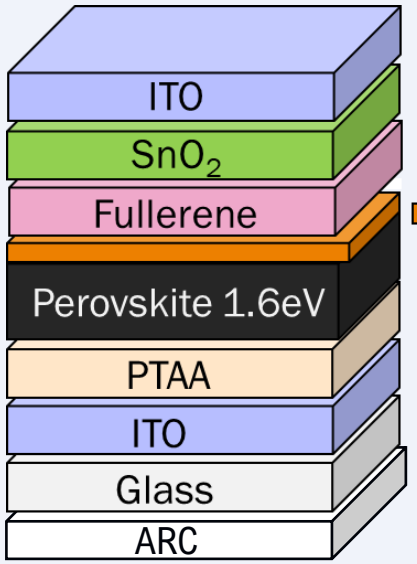
Slot die coating



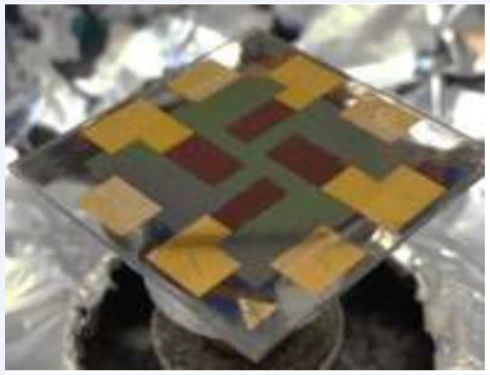
Roughness < 15nm



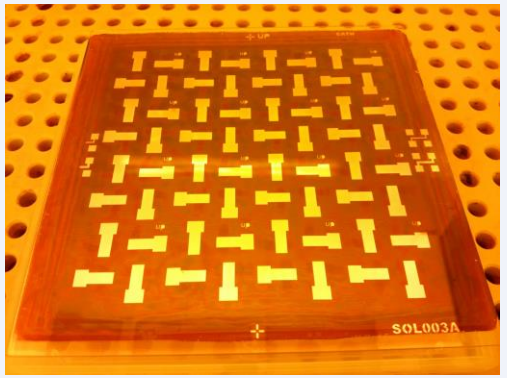
From spin coating to slot die coating



2D PEA-X passivation layer



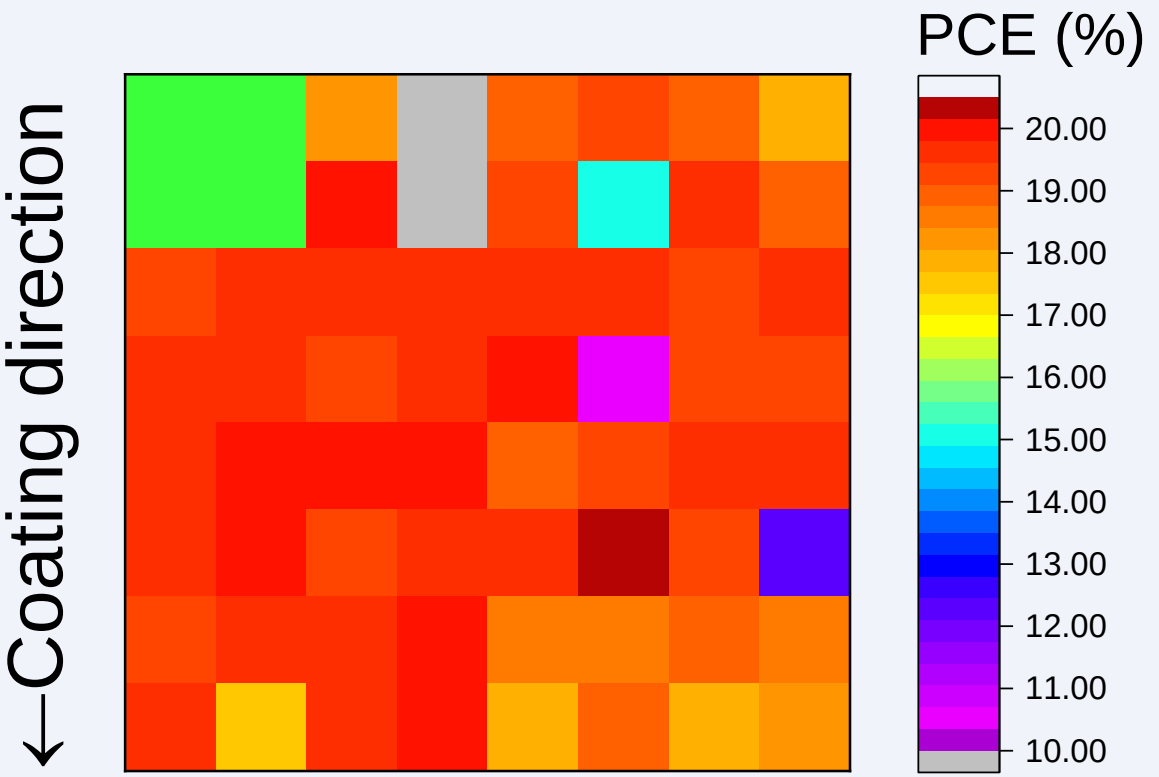
Spin coating
+ gas quenching

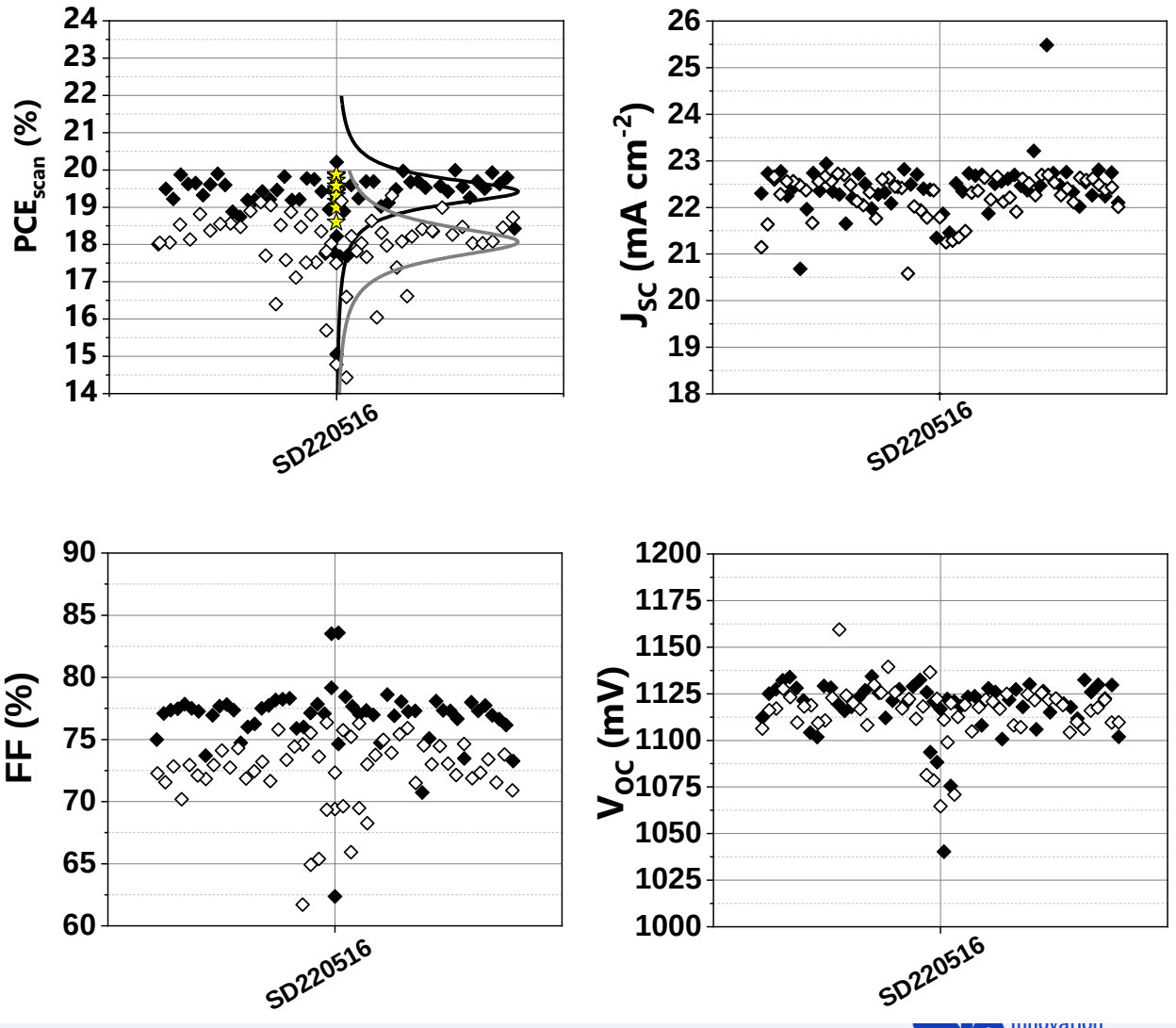


Slot die coating
+ vacuum quenching

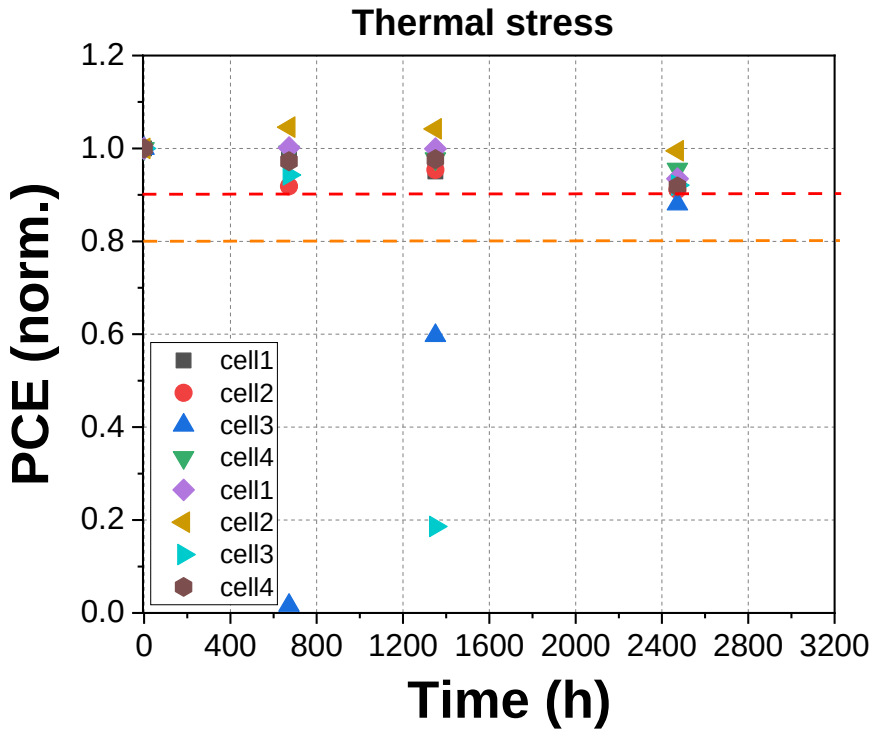
Type		J_{SC} (mAcm^2)	V_{OC} (mV)	FF (%)	PCE (%)	MPPT (%)
Spin coating	REV	21.6	1128	79.8	19.5	19.6
	FORW	21.6	1122	76.8	18.6	
Slot die coating	REV	22.7	1122	77.9	19.9	19.9
	FORW	22.6	1122	75.3	19.2	

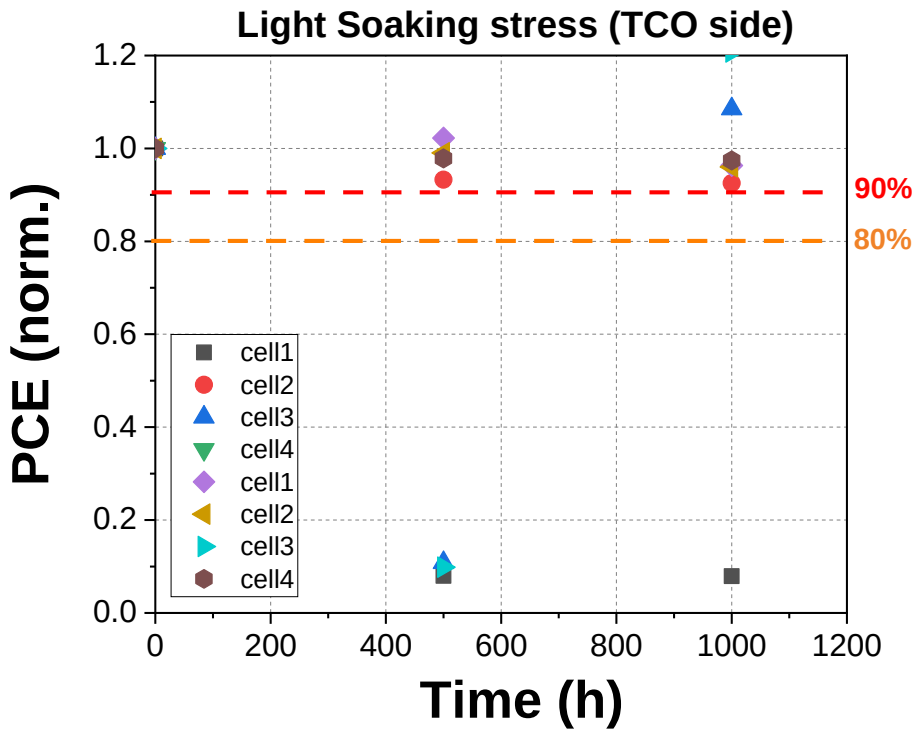
Homogeneity upscaled ST-PSC





Stability of upscaled ST-PSC

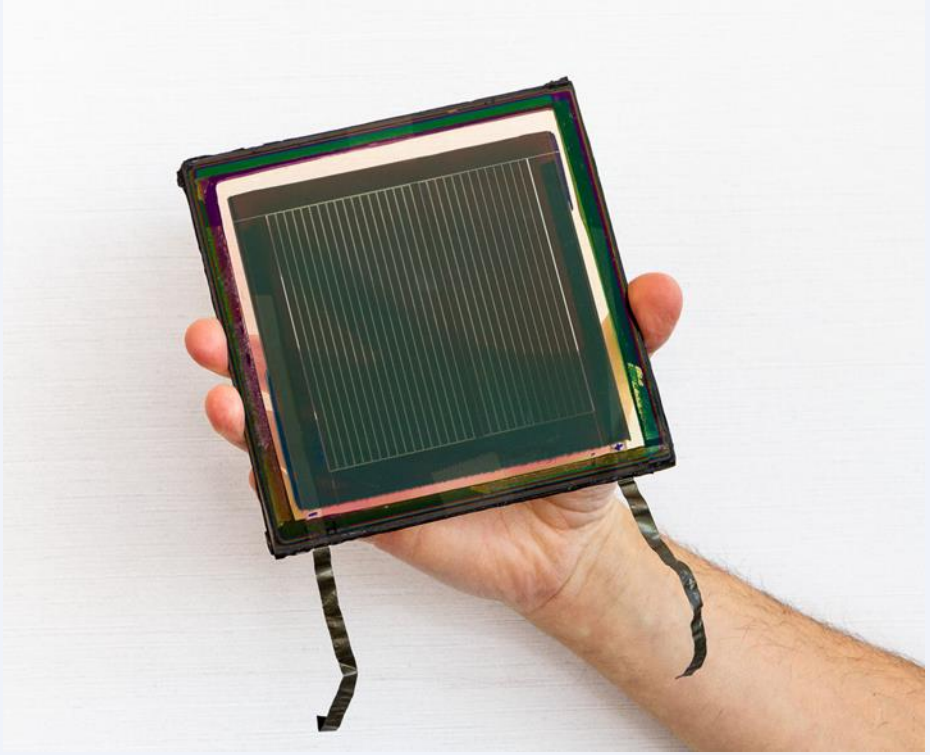




- Unencapsulated ST-PSCs retain more than 90% after 2400hrs under thermal stress (85°C in N_2)
- 1000h light soaking test passed with unencapsulated ST-PSCs (40°C in N_2)

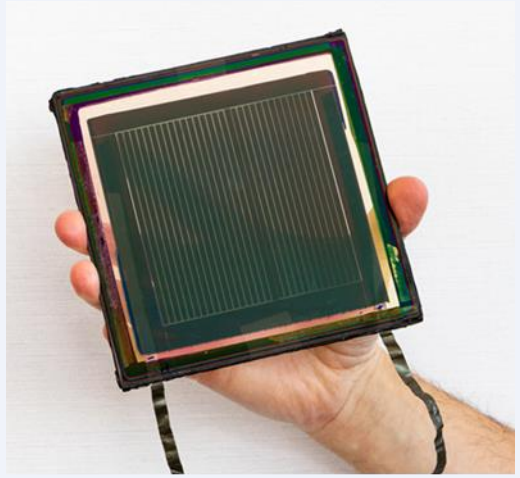
Semitransparent module

- **Current generation semi-transparent modules:**
  - p-i-n architecture
  - Aperture area: 100 cm^2
  - Geometrical FF.: 92%
  - Adopted for 4T architecture with c-Si and CIGS
- **Scalable fabrication**
  - Front TCO: **highly near infrared transparent TCO**
  - Slot die coating for HTL, Perovskite, **passivation layer**
  - **Evaporation fullerene**
  - **Spatial Atomic Layer Deposition**
  - Back TCO: Sputtering ITO
  - Laser patterning for P1,P2,P3



Type		I_{SC} (mA)	V_{OC} (V)	FF (%)	PCE (%)
ST-Module (1.6eV) (100cm^2)	REV	63	35.5	70.5	15.98
	FORW	63	35.2	70.9	15.94
	MPPT				**16.05** **17.4 (act.area)**

Large area 4T area matched Tandem



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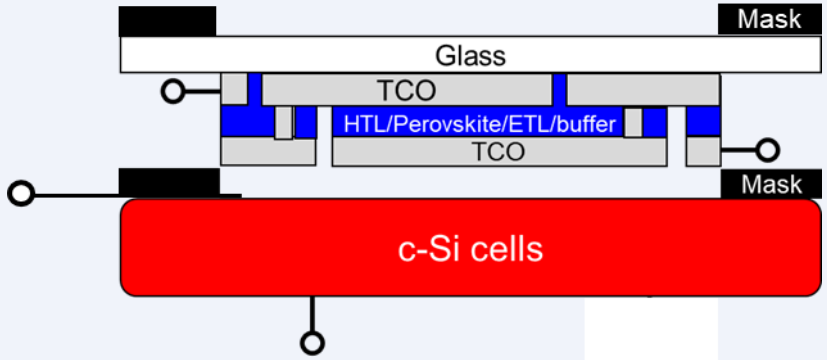
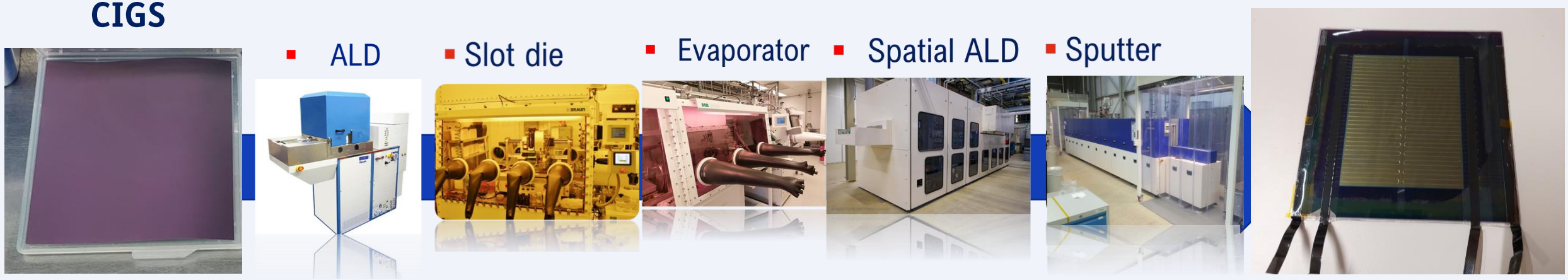


Type		I_{SC} (A)	V_{OC} (V)	FF (%)	PCE (%)
ST-Module (1.6eV) (100cm²)	REV	0.063	35.5	70.5	15.98
	FORW	0.063	35.2	70.9	15.94
	MPPT				**16.05**
SHJ (1.1eV) (Masked 100cm²)	SJ	3.93	0.717	78.8	**22.21**
	Bottom	1.73	0.704	78.8	9.59
4 TANDEM					**25.64**

From glass to c-Si and flexible CIGS bottom cells

Commercial c-Si

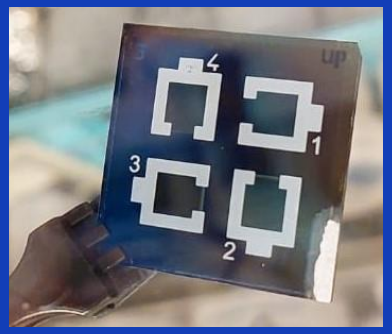
Commercial flexible CIGS

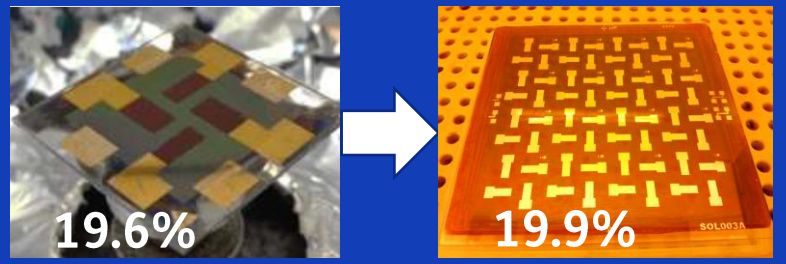


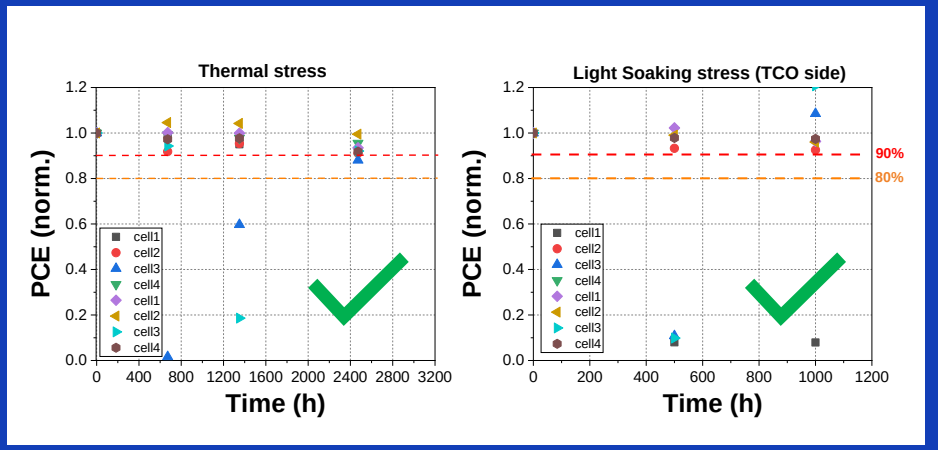
Theme name

Conclusion

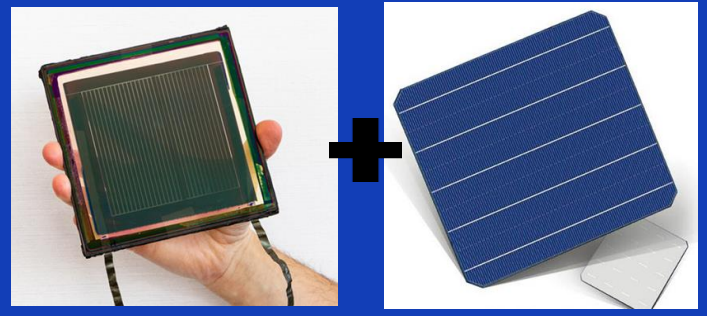
- **High efficient SJ (>20%) and hybrid tandem PSC-CIGS (24.6%)**
- No performance loss in scaling up
- **Light** and **thermal stability**
- **25.6%** PCE for 100 cm^2 area-matched **4T PSC/c-Si tandem**
- **First prototypes of large area 2T PSC/CIGS and PSC/c-Si**



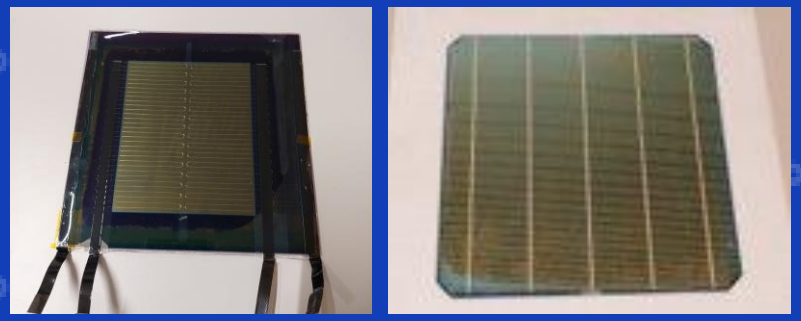




4T area matched



2T hybrid tandems



Thank you for your attention

Acknoledgment

TNO

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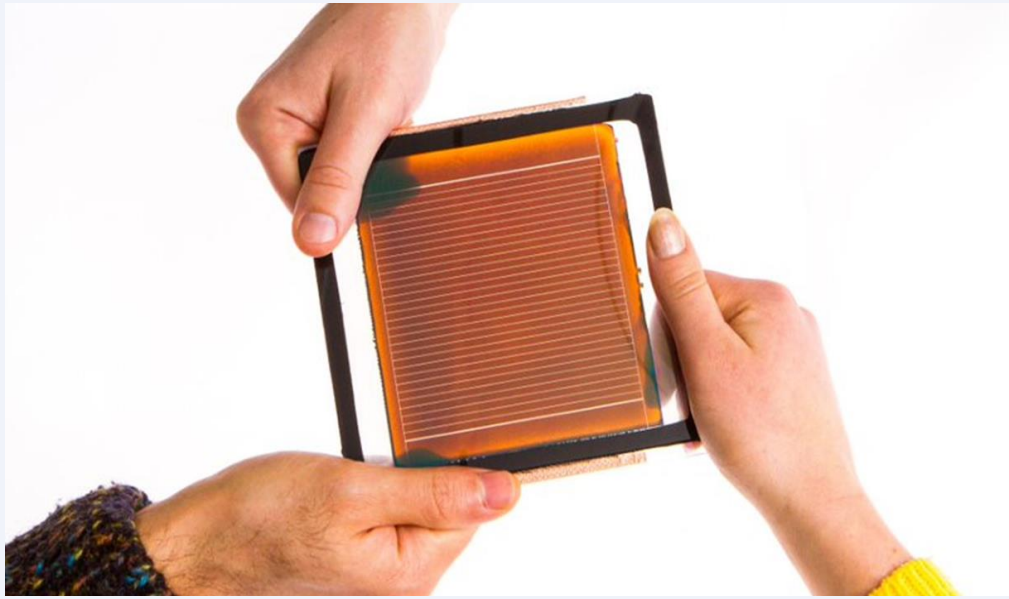
Junke Wang
Kunal Datta
Kousumi
Andrea Bracesco
Martijn Wienk
Adriana Creatore
Rene Janssen



- **Contact**
- valerio.zardetto@tno.nl

Thank you for your attention

Funding

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LIMITLESS (TKI-PPS, TEUE1921202)
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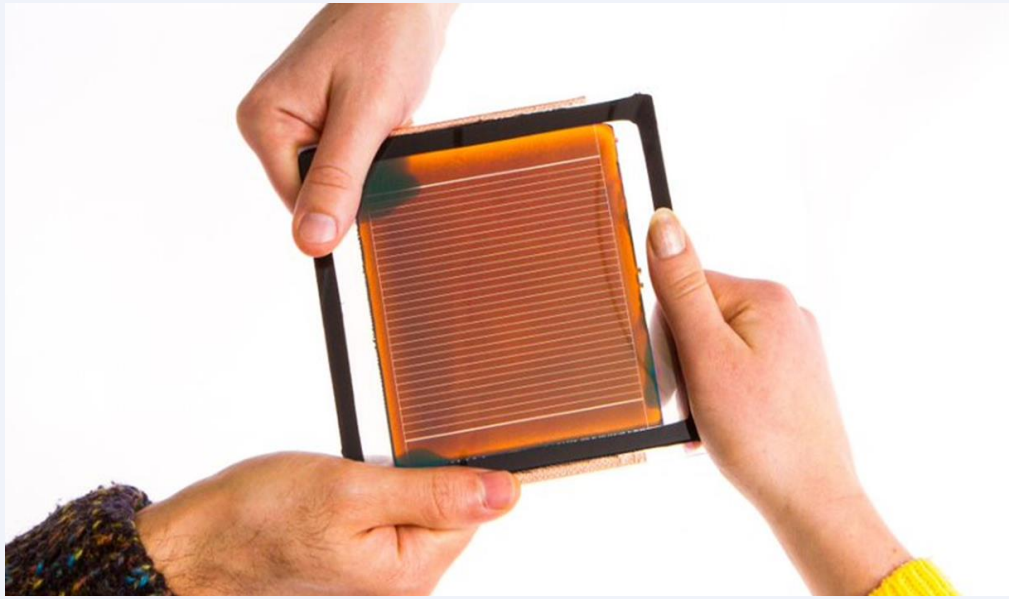
FIT4MARKET (HER+21-02920432)



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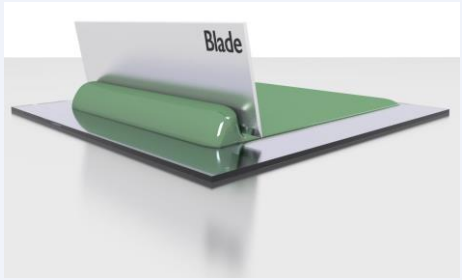
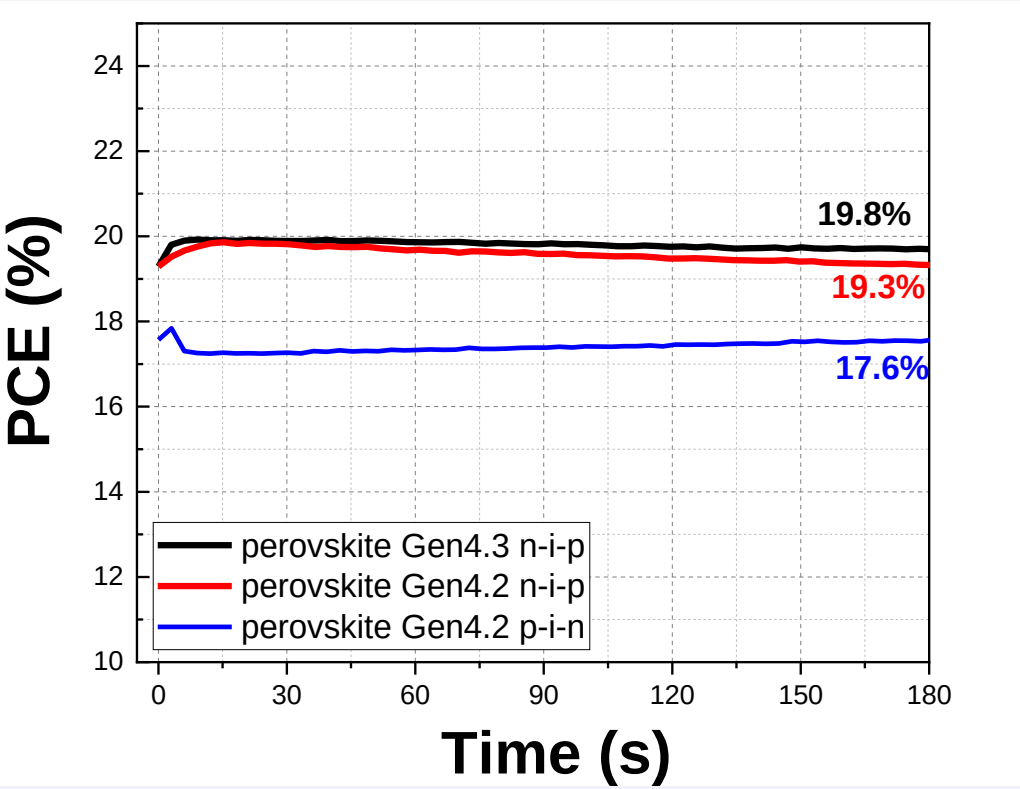
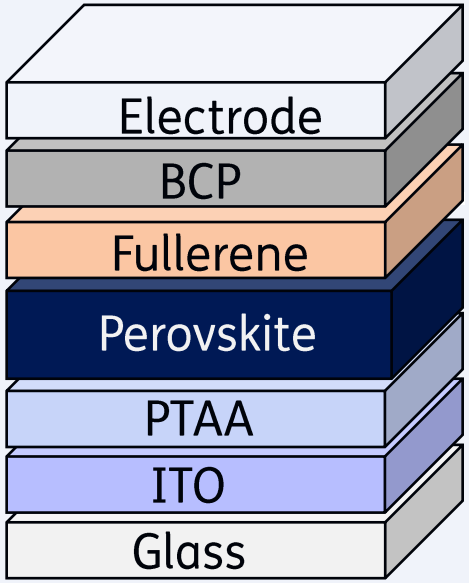
Lab scale efficient perovskite solar cells



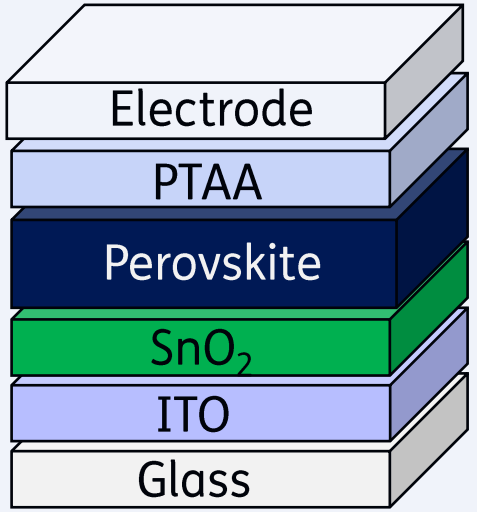
Blade coat of the perovskite with enviromentally friendly perovskite ink

Antisolvent quenching





p-i-n



n-i-p