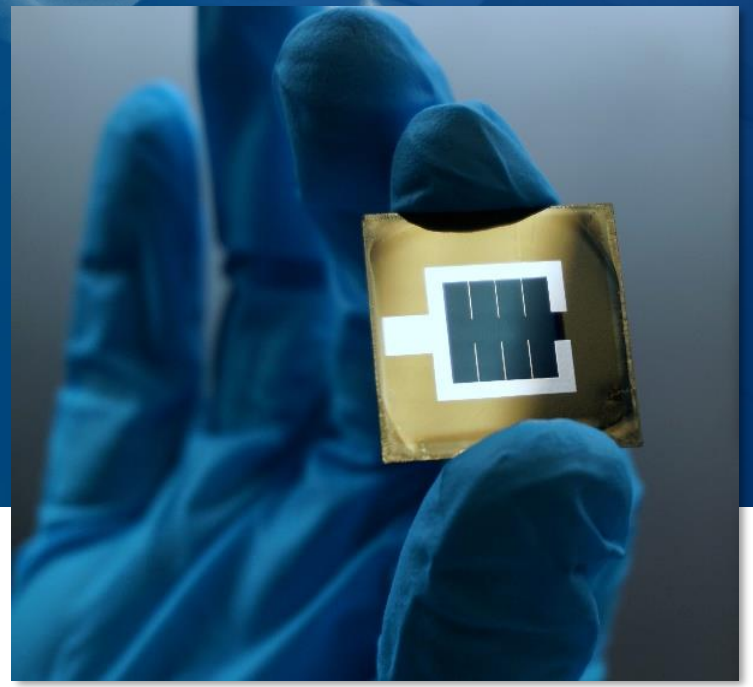
HZB Helmholtz Zentrum Berlin

PEROVSKITE/SILICON TANDEM TECHNOLOGIE

STAND & PERSPEKTIVEN DER INDUSTRIALISIERUNG

Prof. Dr. Bernd Stannowski



***PTJ** – PV Dialog im Forschungsnetzwerk Erneuerbare Energie*
Webinar 10.10.2024

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Prof. Steve Albrecht	Perovskite-based multijunctions, Evaporation, Stability
Prof. Antonio Abate	Stability, Lead-free Perovskites
Prof. Eva Unger	Solution Process, Scaling, Hybrid Materials
Prof. Emil List-Kratochvil	Ink-Jet Printing (HU Berlin)

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BMBF:	PeroWin, …
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The project is also supported by the Swiss State Secretariat for Education, Research and Innovation (SERI).

Inhalt

- Tandemsolarzellen

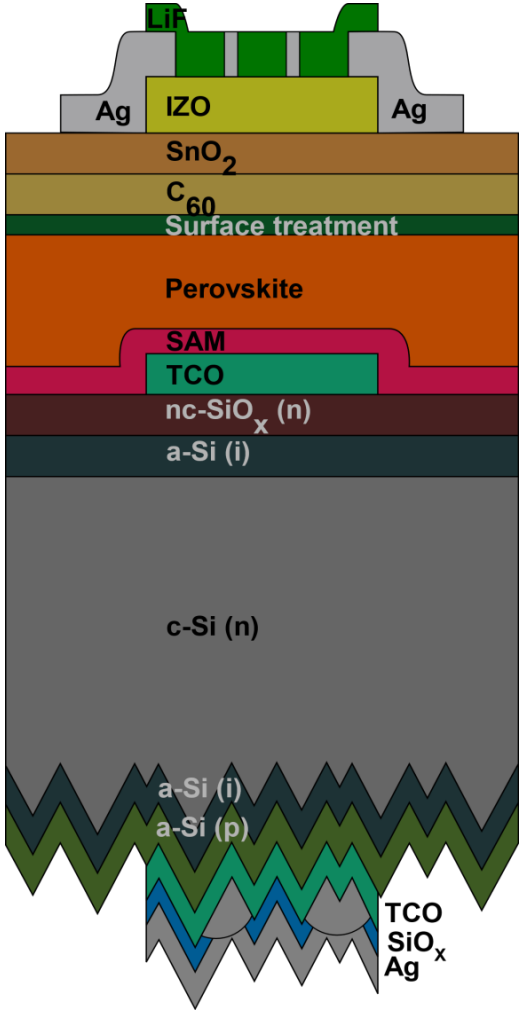
  Warum braucht man die?

- Perowskite

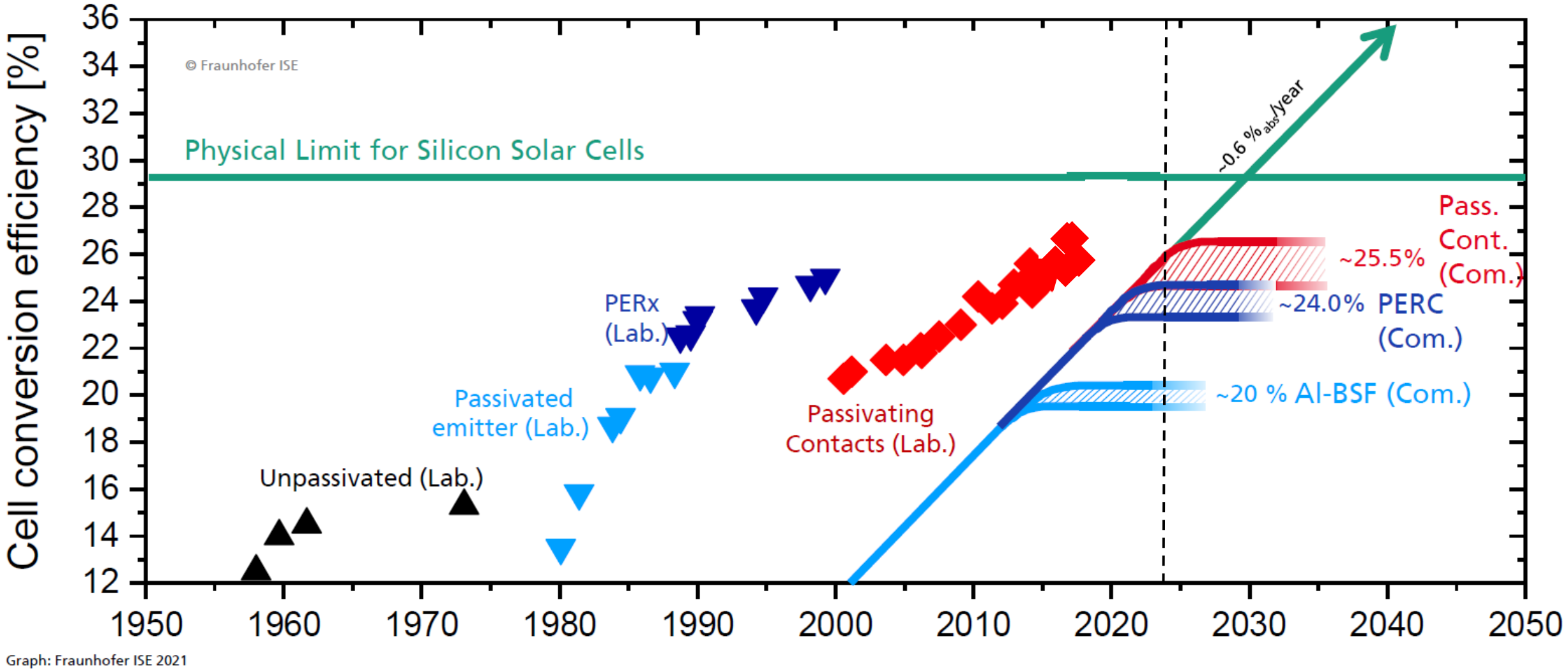
  Warum so erfolgreich?

- Skalierung

  Wie geht das?



Silicon Solar Cell Technologies: From R&D to Commercialization

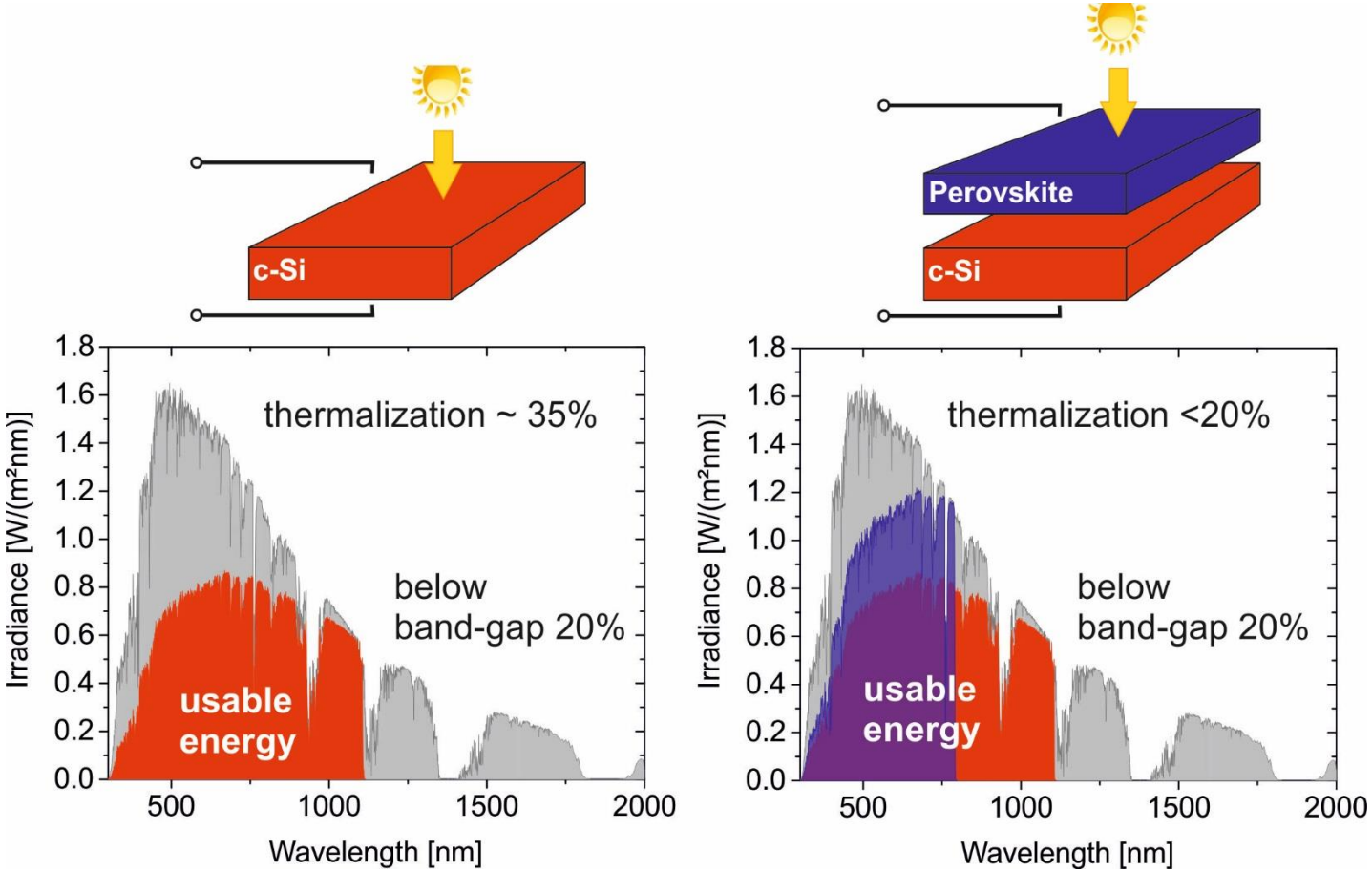


Graph: Fraunhofer ISE 2021

adapted from „ISE photovoltaics report 2022“, www.ise.fraunhofer.de

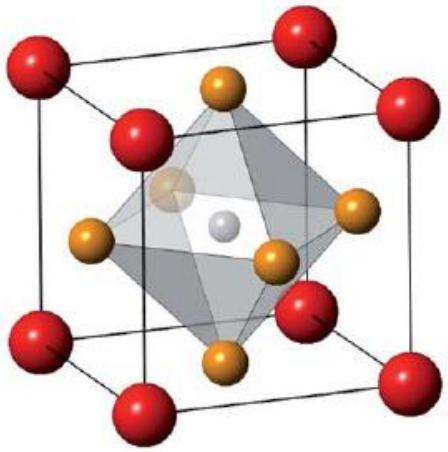
Principle of a Tandem Solar Cell

- high loss from thermalization



- high energy photons are absorbed by perovskite
  - converted at a high voltage
  - reduced losses from thermalization
- infrared photons are transmitted into c-Si
  cover a wide spectral range of absorption

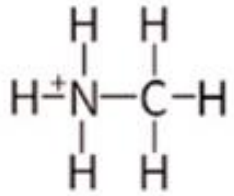
Metal-Halide Perovskites



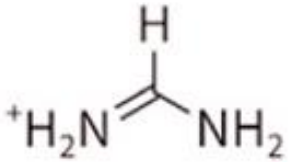
A MA^+, FA^+, Cs^+

B Pb^{2+}, Sn^{2+}

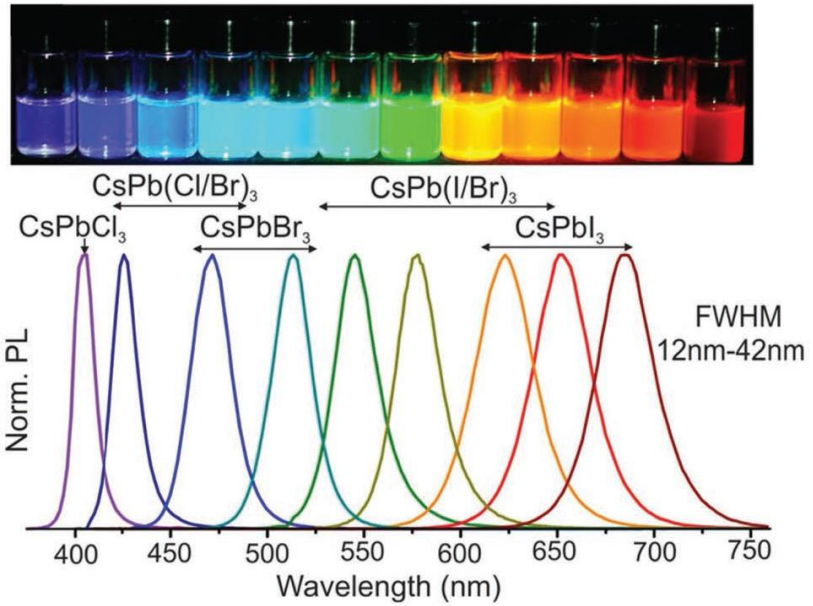
X Br^-, I^-, Cl^- (halide)

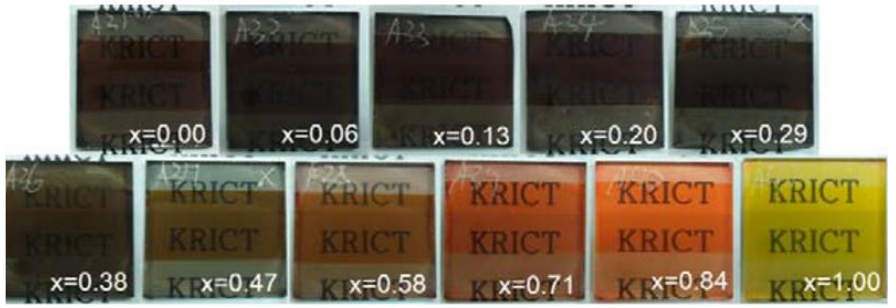


Methylammonium (**MA**)



Formamidinium (**FA**)

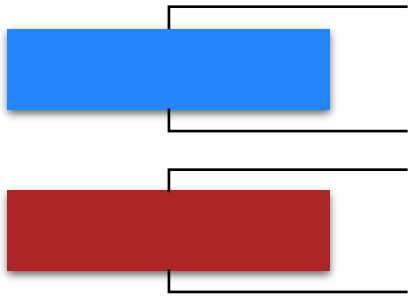




- **Variable bandgap** (lattice constant) by halide substitution
  e.g. „Triple Cation“: $Cs_{0.05}(FA_{0.77}MA_{0.23})_{0.95}Pb(I_{0.77}Br_{0.23})_3$ (E_g=1.68eV)
- Simple Processing @ **Low cost**
- **Sensitivity** to temperature, moisture, light, …

Snaith et al., Energy Environ. Sci., 2014, 7, 982

Tandem Device Concepts



$P=P_1+P_2$

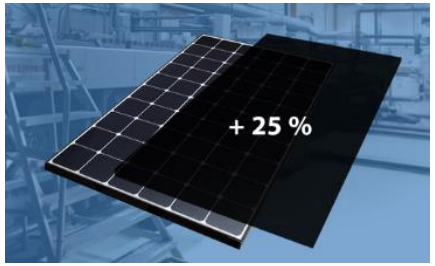
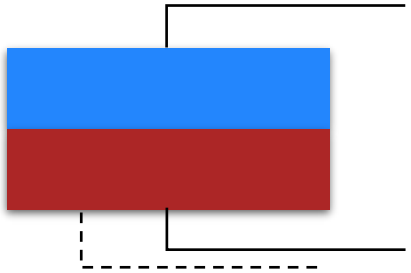


image: https://www.evolarab.se/technology

4-Terminal (or: 2-Terminal Voltage matched modules)

- Dedicated fabrication Lines
- Ideal MPP tracking (matching)
- More contacts needed (TCO)
- (more system components, BOS)



$P=I(U_1+U_2)$

2 Terminal, monolitic cell (or 3-Terminal on IBC)

- Simple electrical connection
- Less material + wires than 4T
- Restrictions in Processing of top cell
- Good optical management needed

SQ Limits

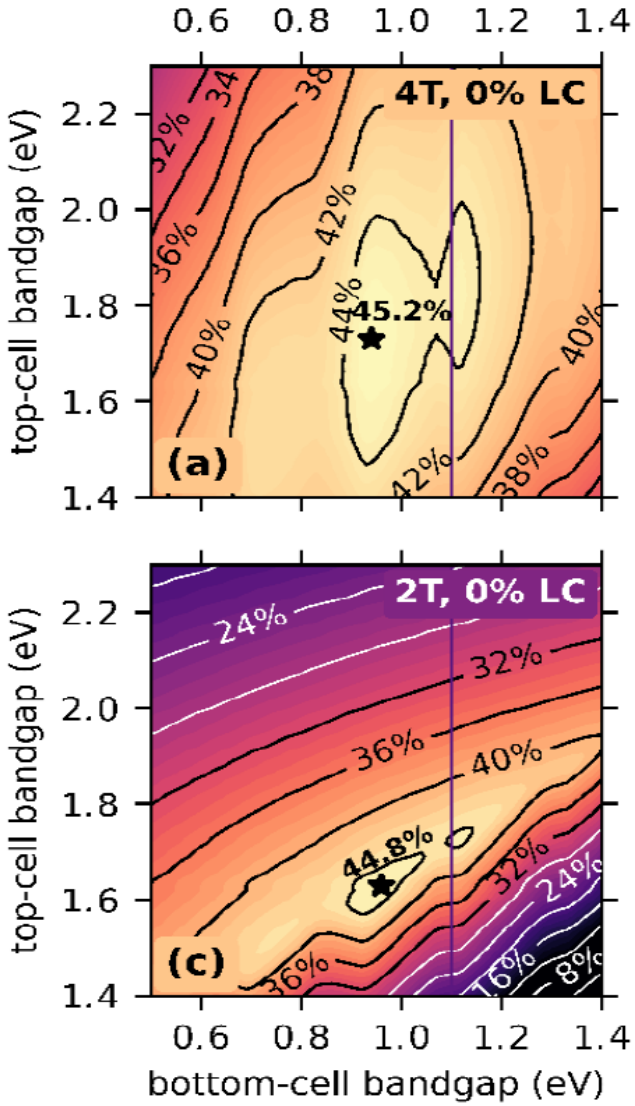
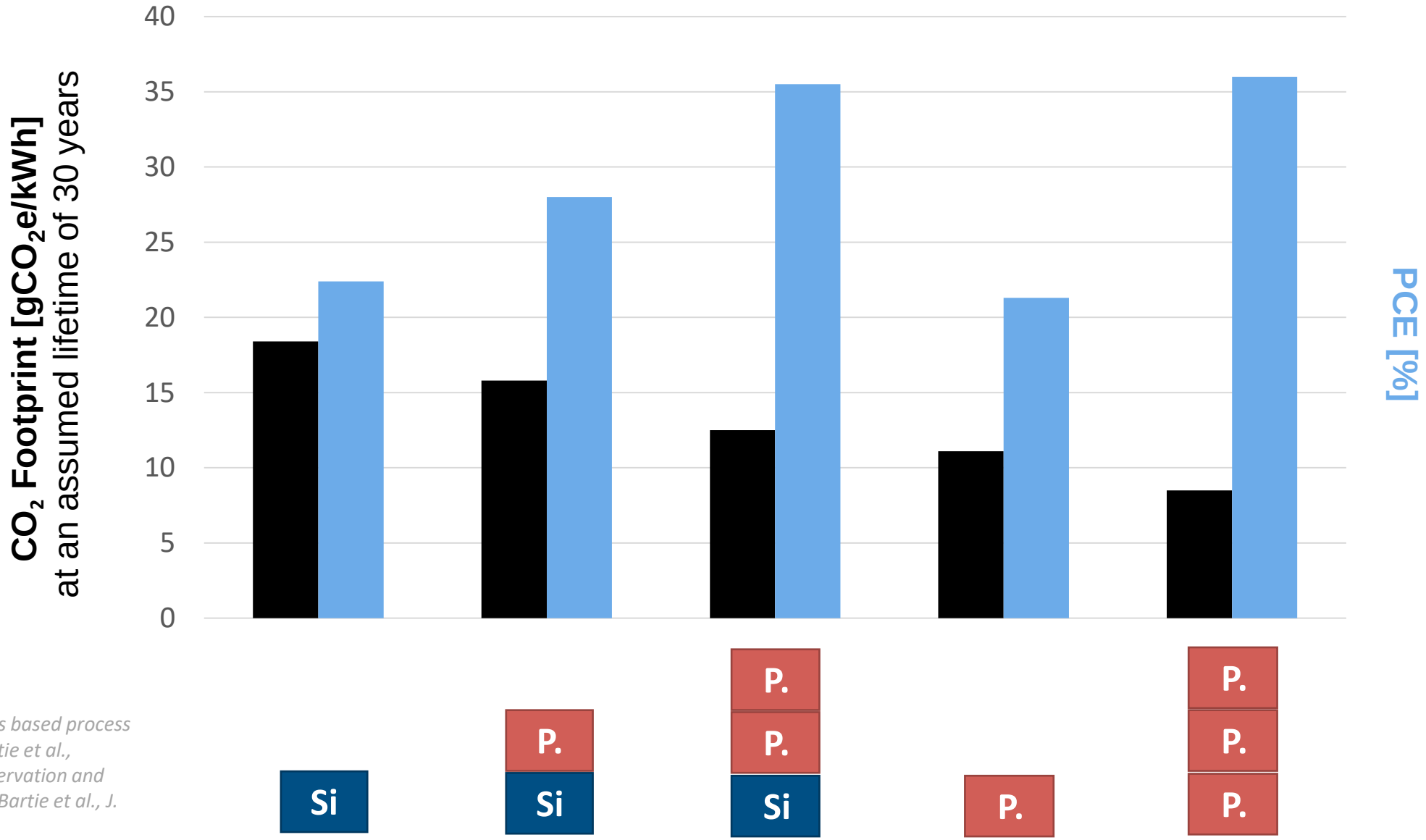


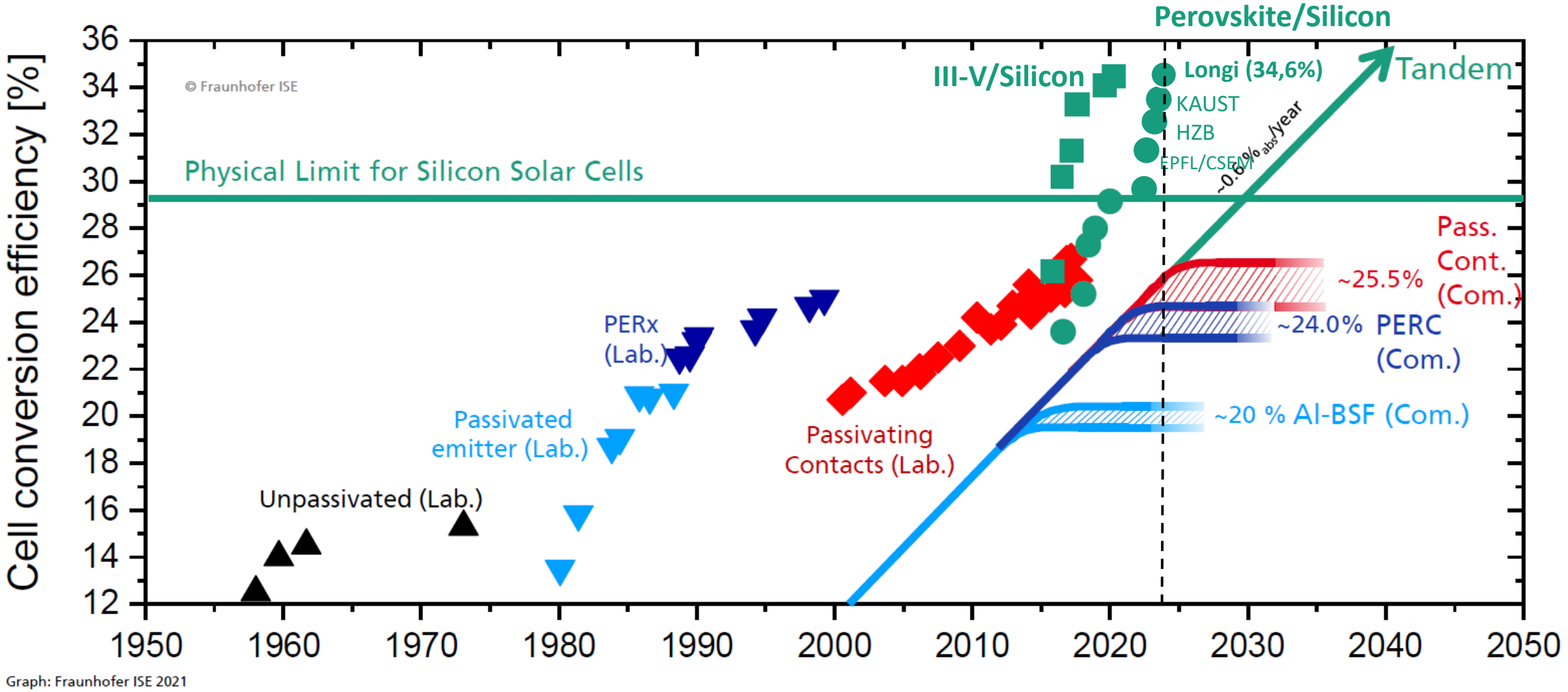
Image: courtesy Klaus Jäger (HZB)

Multijunctions to reduce CO_2 footprint



Thermodynamics based process simulations: Bartie et al., Resources, Conservation and Recycling, 2021 Bartie et al., J. Ind. Ecol. 2023

Silicon Solar Cell Technologies: From R&D to Commercialization

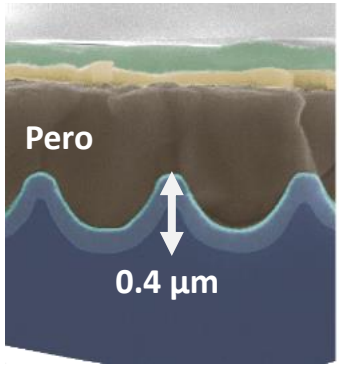


Graph: Fraunhofer ISE 2021

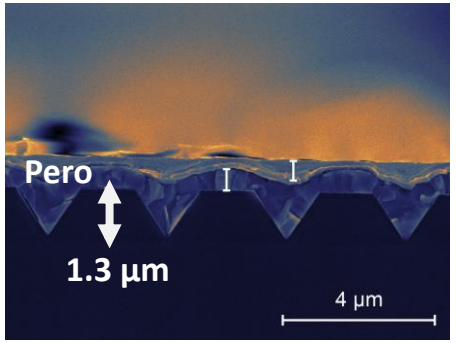
adapted from „ISE photovoltaics report 2022“, www.ise.fraunhofer.de

Tandem cell development @ HZB

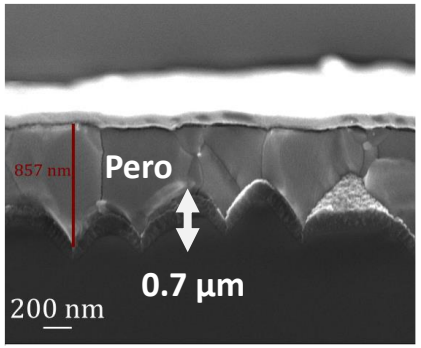
Perovskite top cells on various silicon topographies



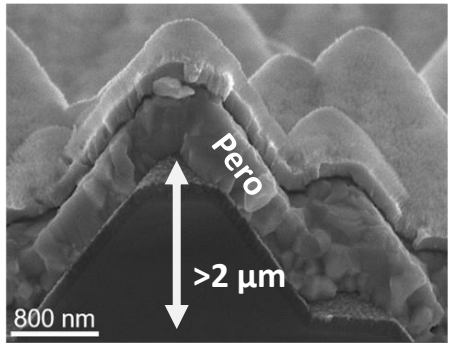
Periodic sinusoidal



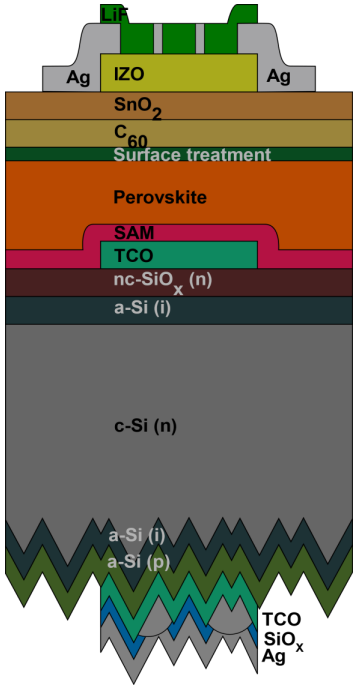
Periodic inverted pyramids

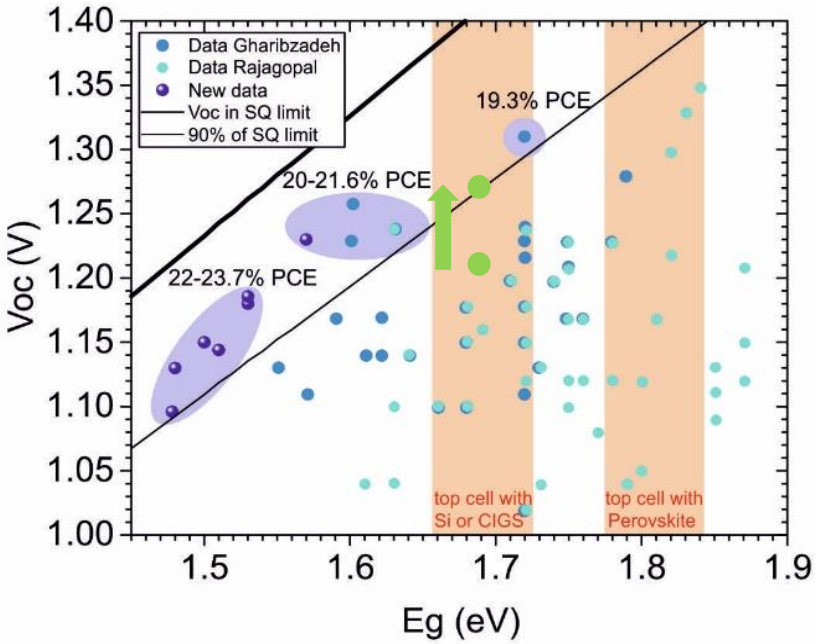


Random sub-µm pyramids



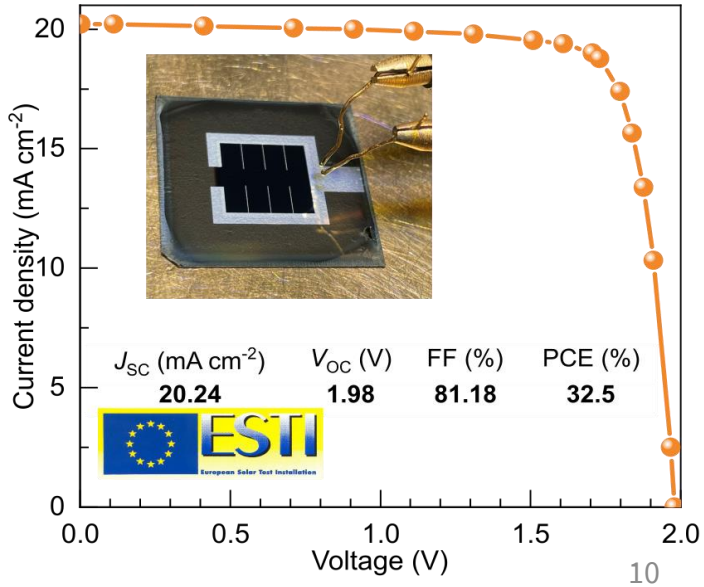
Standard random pyramids





Advanced Passivation, Electron & Hole-transport layers (ETL, HTL) lead to V_{oc} = 2 V

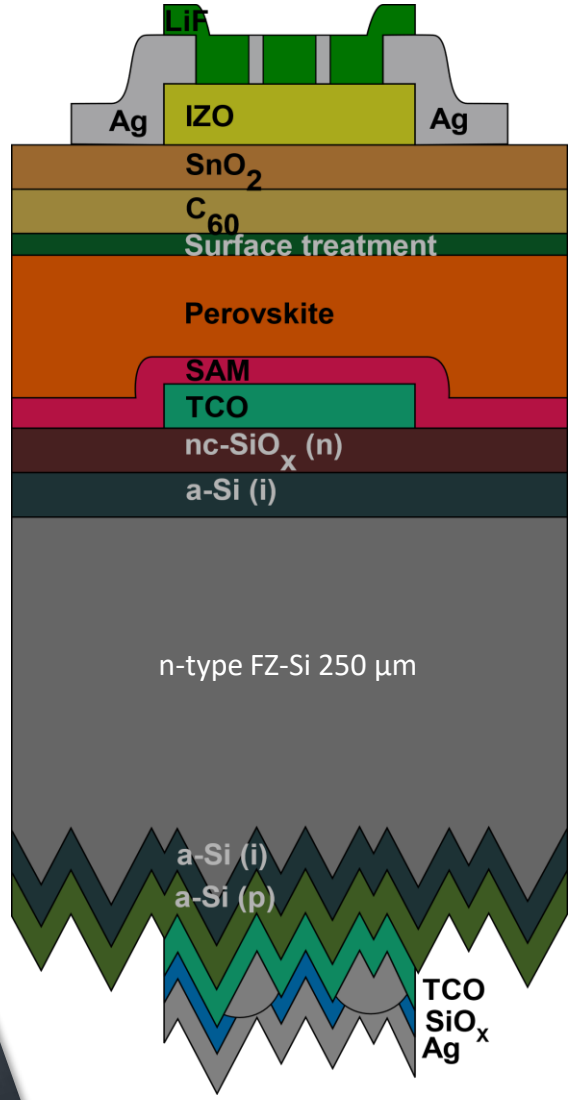
World Record of 32.5%



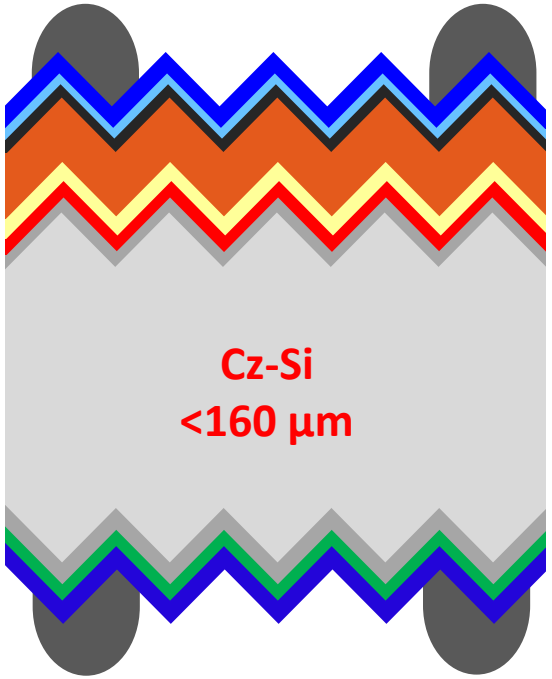
Mariotti, Köhnen, Scheler et al., Science 381 (2023)

Upscaling: How from Lab to Fab?

Lab cell



Industrial cell



Low-damage & low-T front electrode

Ag grid

TCO

ETL / buffer

Perovskite → Which Process?

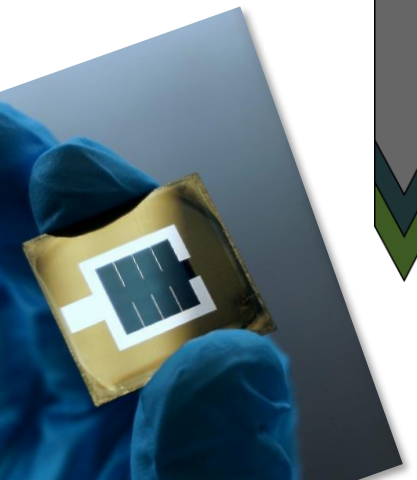
HTL

i/n nc-Si:H → Texture !?

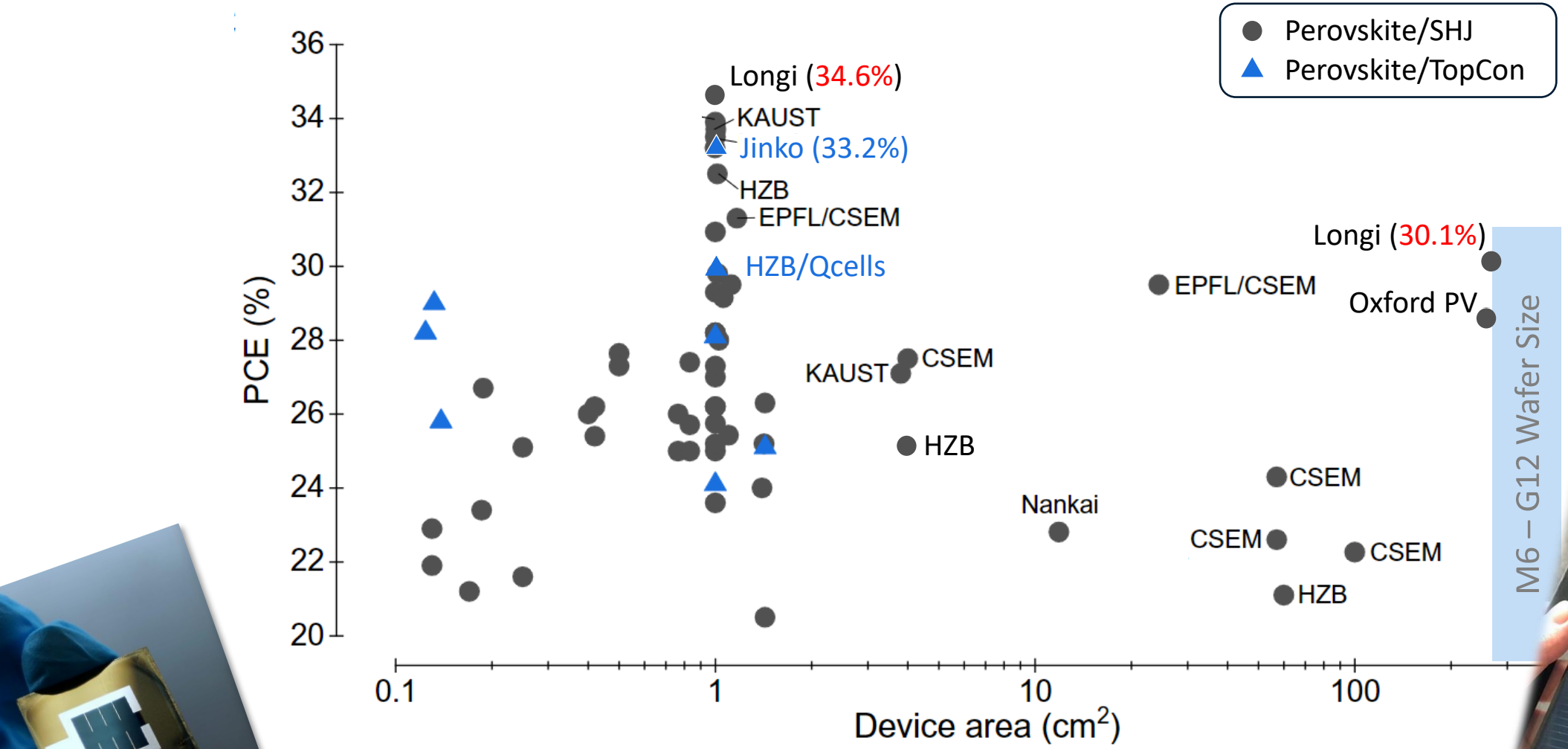
i/p a-Si:H

TCO

Ag grid



Upscaling of Monolithic Perovskite/Silicon Tandem Cells



Adapted from E. Aydin et al., Science 383 2024, https://doi.org/10.1126/science.adh3849

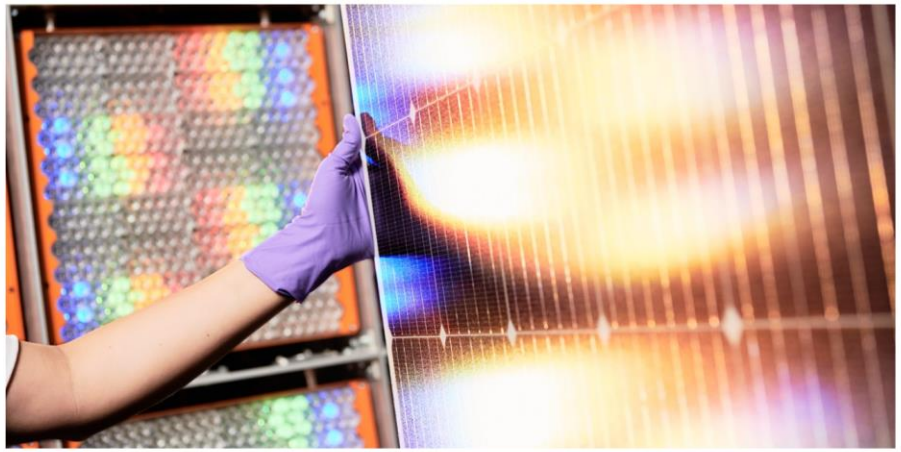
First commercial tandem modules …

Oxford PV präsentiert Tandemmodul mit 26,9 Prozent Wirkungsgrad

Der Hersteller hat sein Modul mit Perowskit-Silizium-Tandemzellen vor allem für Hausdächer konzipiert. Es soll in 12 bis 18 Monaten verfügbar sein. Zudem will das britische Unternehmen zusammen mit Sunmaxx ein PVT-Modul mit Tandemzellen auf den Markt bringen.

20. JUNI 2024 RALPH DIERMANN UND PATRICK JOWETT

HIGHLIGHTS DER WOCHE | MÄRKTE | DEUTSCHLAND | EUROPA | GLOBAL



Oxford PV hat Anfang des Jahres den Prototypen eines zusammen mit Forschern des Fraunhofer ISE entwickelten Perowskit-Silizium-Moduls vorgestellt, das auf 25 Prozent Wirkungsgrad kommt.

Foto: Fraunhofer ISE

https://www.pv-magazine.de/2024/06/20/oxford-pv-praesentiert-tandemmodul-mit-269-prozent-wirkungsgrad/

OXFORD PV™

Oxford PV startet kommerziellen Vertrieb von Perowskit-Tandem-Solarmodulen mit 20 % mehr Energieoutput

Donnerstag, 5 September 2024

https://de.oxfordpv.com/news/oxford-pv-startet-kommerziellen-vertrieb-von-perowskit-tandem-solarmodulen-mit-20-mehr

China follows …

GCL says perovskite solar module passes silicon degradation tests

At Intersolar Europe, the Chinese manufacturer also said the perovskite-silicon tandem module would cost 50% of a crystalline silicon module that costs $0.15 per W, meaning $0.075 per W.

JUNE 20, 2024 JOHN FITZGERALD WEAVER

MODULES & UPSTREAM MANUFACTURING | TECHNOLOGY AND R&D | CHINA

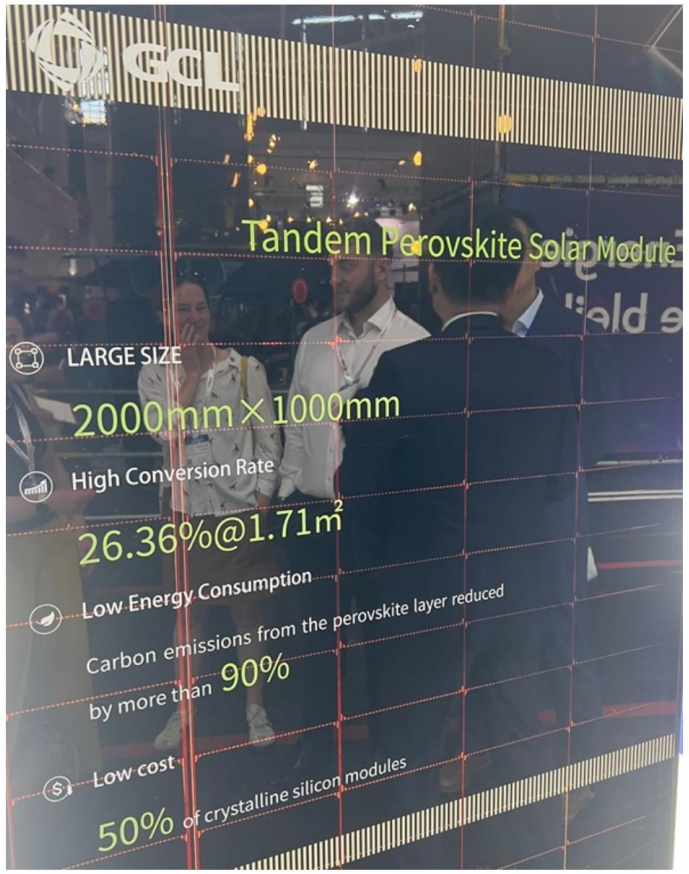


Image: pv magazine

https://www.pv-magazine.com/2024/06/20/gcl-says-perovskite-solar-module-passes-silicon-degradation-tests/

China‘s perovskite single junction modules

Commercial perovskite solar modules at SNEC 2024 trade show

China’s Utmo Light showcased its first full perovskite PV module at this week’s SNEC PV trade fair in Shanghai, underscoring the technology’s ongoing shift toward commercialization.

JUNE 13, 2024 MARIAN WILLUHN

RESIDENTIAL PV | TECHNOLOGY | TECHNOLOGY AND R&D | CHINA

Utmo Light President Zhenrui Yu

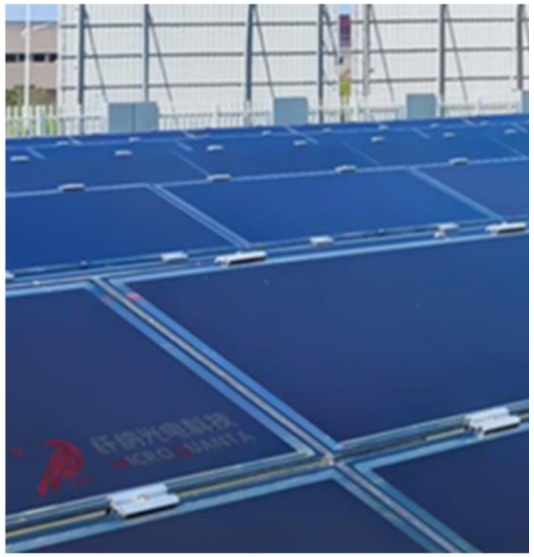
Image: pv magazine, Marian Willuhnn

https://www.pv-magazine.com/2024/06/13/commercial-perovskite-solar-modules-at-snec-2024-trade-show/

1GW Perovskite! Microquanta’s Module Manufacturing Project Approved in China

JUNE 24, 2024 BY ALEINA IN PROJECTS

PVTIME – Microquanta, a leader in perovskite photovoltaic technology, manufacturing and applying perovskite modules for utility-scale solar farms and BIPV, recently a
scale perovskite solar manufacturing base has been approved by th



https://www.pvtime.org/1gw-perovskite-microquantas-module-manufacturing-project-approved-in-china/

China Three Gorges commissions 1 MW pilot PV plant with perovskite panels

China Three Gorges has commissioned a 1 MW pilot solar plant with perovskite panels near Ordos, in China’s Inner Mongolia region. This marks the world’s first commercial PV system to use perovskite tech and features 11,200 modules from an undisclosed manufacturer.

DECEMBER 4, 2023 EMILIANO BELLINI

MODULES & UPSTREAM MANUFACTURING | TECHNOLOGY AND R&D | UTILITY SCALE PV | ASIA | CHINA

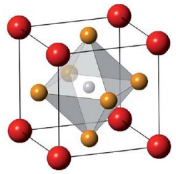
The Kubuqi Photovoltaic Desert Control Project

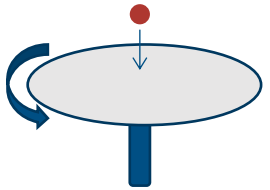
Image: China Three Gorges Corporation

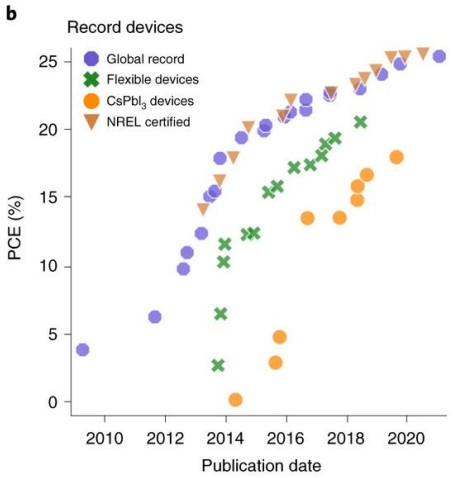
https://www.pv-magazine.com/2023/12/04/china-three-gorges-commissions-1-mw-pilot-pv-plant-with-perovskite-panels/

Process Routes for Upscaling

Lab: Spin Coating

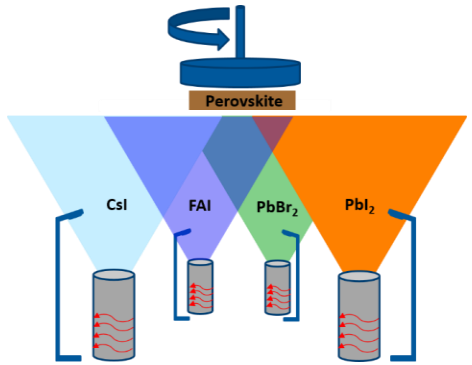




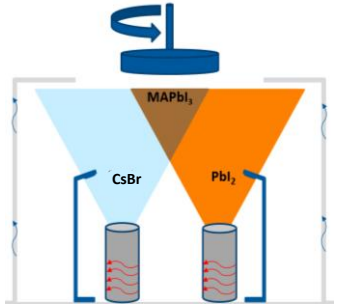


(1) Solution process, e.g. Slot-Die Coating

(2) Vapor-phase deposition (Co-)evaporation in vacuum



(3) Hybrid Process



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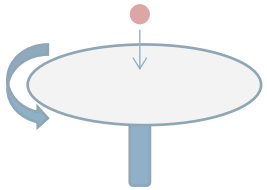
T. J. Jacobsson et al. E. Unger, *An open-access database and analysis tool for perovskite solar cells based on the FAIR data principles,* Nature Energy 2022

Process Routes for Upscaling

(1) Solution process, e.g. Slot-Die Coating

Lab: Spin Coating



Advantages

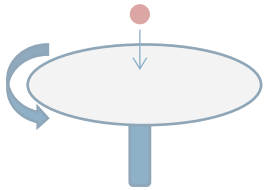
- Low Capex
- Easy to modify ink, e.g. additives

Challenges

- Wafer topography & edges
- Uniform layer conversion
- Solvent handling

Process Routes for Upscaling

Lab: Spin Coating



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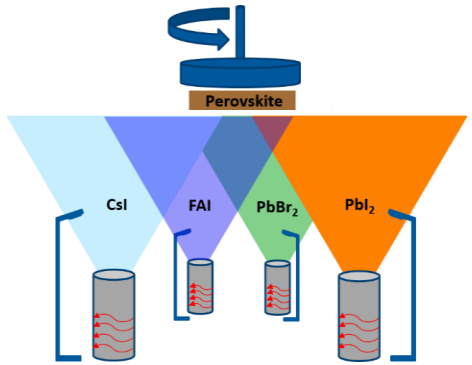


Advantages

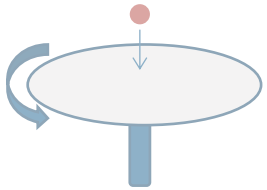
- Large scale production
- Conformal growth
- No solvents

Challenges

- High Capex / Low throughput (evap. rate)
- Not flexible in choice of materials
- Poor process stability

Process Routes for Upscaling

Lab: Spin Coating



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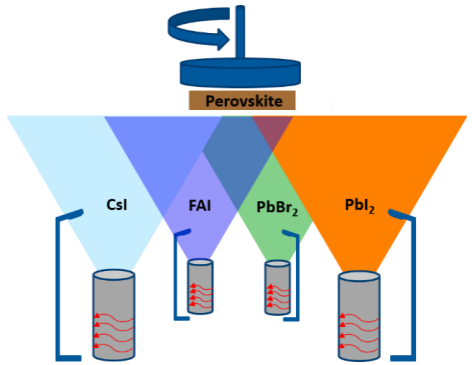
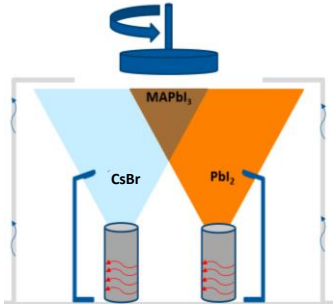


(3) Hybrid Process



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Combining
Advantages
or
Challenges
?

Pero/Silicon Tandem Line

Industrial Bottom Cells

Laser (Keyence)

Arias Wet Benches

Indeotec Octopus II

LeyboldOptics A600V7

rias Wet Bench

KOALA Cluster Von Ardenne-CreaPhys

ASYS-EKRA

Laminator

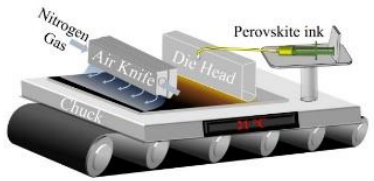
Laser cutting & labelling → **Wet Bench** SDE-Tex-Clean → **Wet Bench** HF, rinse, dry → **PECVD** a-Si i/n i/p → **Sputter** TCO rear +front → **Wet Bench Clean +Anneal + SAM** → **KOALA Cluster** (PERO vap | OPTI vap | ALD | Sputter) → **Screen Printing** Metal grid front, rear → **Lab Modules**

Batches of up to 12 wafers M6

QSSPC

PL

Slot Die Pero



WaveLabs Sinus220/300

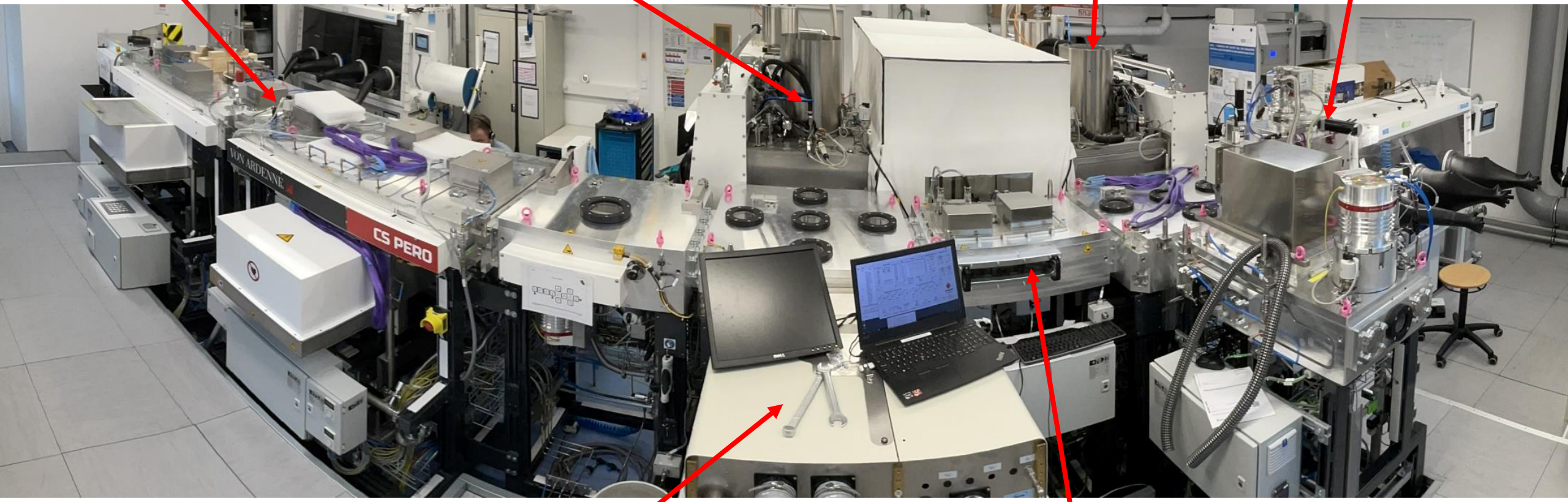
IV + grid Rs + TLM

EQE

EL/PL

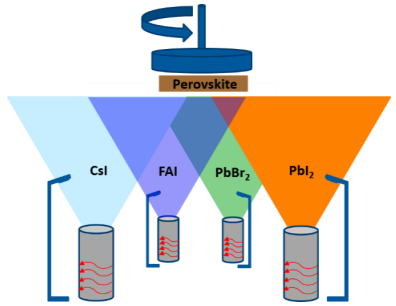
Indoor & Outdoor Testing

Perovskite Cluster Tool („KOALA“)



Full-vacuum processed Perovskite @HZB

Co-evaporation

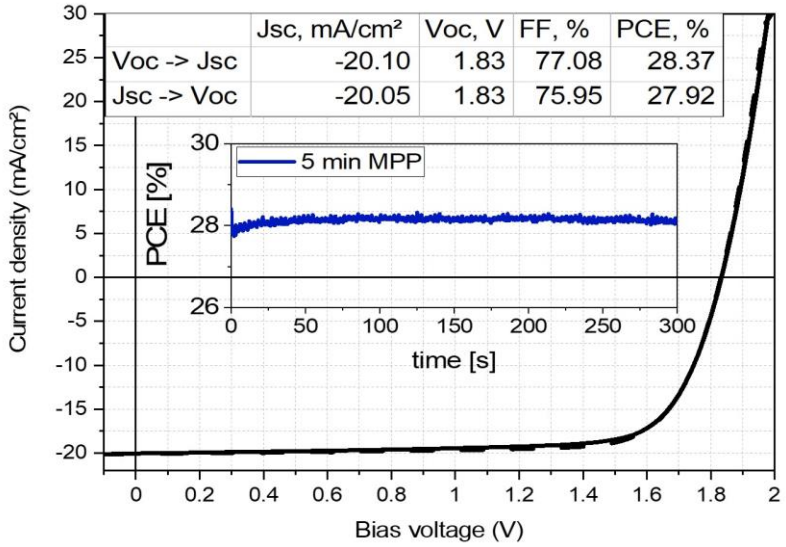


Wide band gap: 1.67 eV

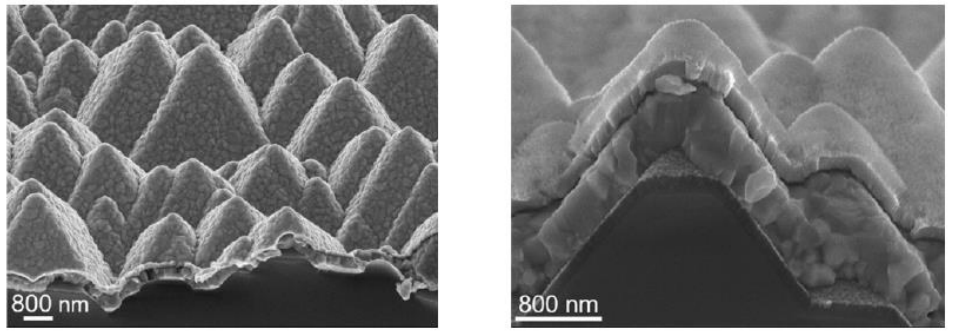
$Cs_{0.20}FA_{0.89}PbI_{2.76}Br_{0.32}$

Viktor Škorjanc *et al.*, TandemPV 2023

Tandem PCE = **28 %** (1 cm², flat Si)

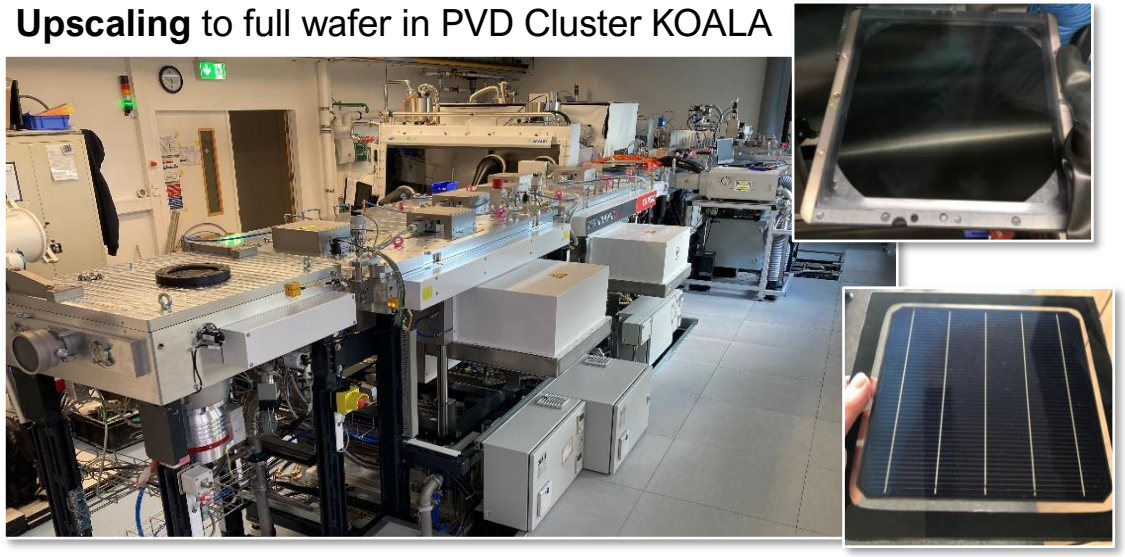


Conformal coating on textured Silicon possible



Marcel Roß *et al.*, Adv. Energy Mater. 2021

Upscaling to full wafer in PVD Cluster KOALA



Advantages

- No wet processes (no solvents)
- Conformal deposition on texture
- Proven in industrial production

Challenges

- Homogeneous perovskite over full wafer
- Reproducible quality (process control)
- Low rates for organics: Low throughput. high CAPEX

Thank you! …Questions?