Shingling meets perovskite-silicon heterojunction tandem solar cells

V. Nikitina[1], C. Reichel[1], D. Erath[1], S. Kirner[2], A. Richter[2], T. Roessler[1], A. De Rose[1], A. Kraft[1], H. Neuhaus[1]

[1] Faunhofer Institute for Solar Energy Systems
[2] Oxford PV Germany

11th Metallization and Interconnection Workshop
Neuchâtel (Switzerland), 9.05.2023
www.ise.fraunhofer.de

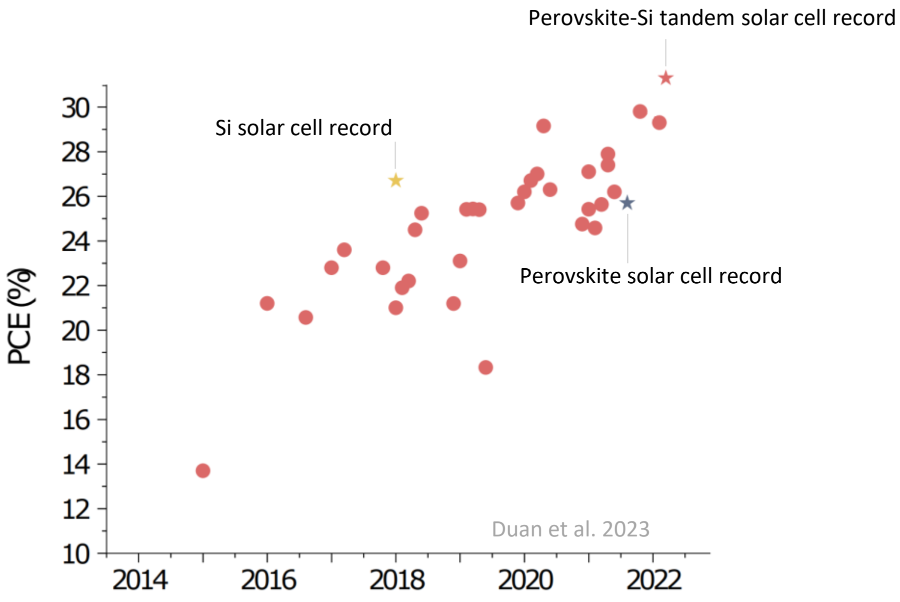
Introduction

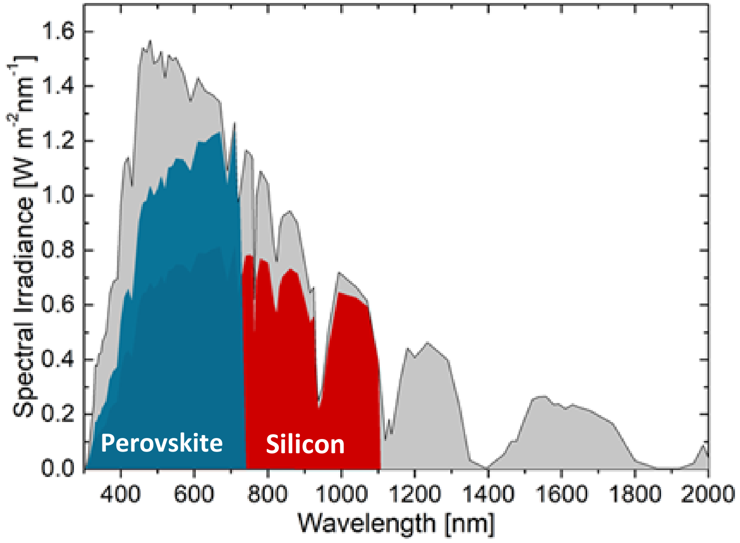
Perovskite-Si Tandem Solar Cells

- Cell concept
  - Top cell – perovskite
  - Bottom cell – crystalline silicon
- Allows harvesting broader range of solar spectum, resulting in higher power conversion efficiency (PCE)

- Rapidly advancing cell technology
  - PCE in 2016 – 13.7%[1], 2023 – 33.2%[2]
- Theoretical efficiency limit over 40%[3]

- Challenges for module integration[4]
  - Environmental influence sensitivity
  - Material selection
  - Process definition at industrial equipment



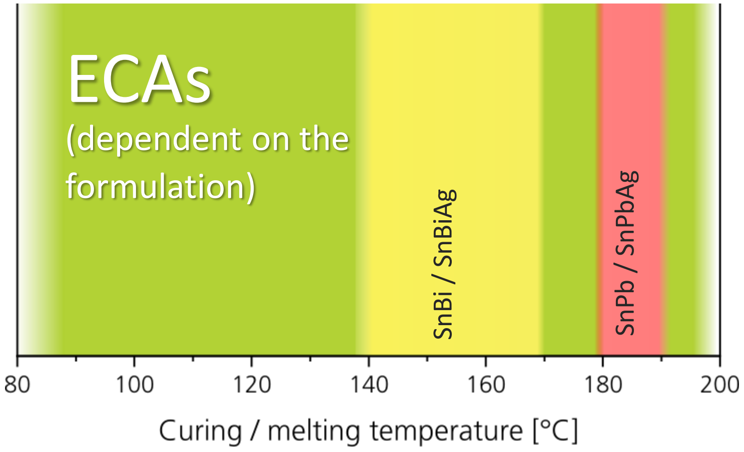


[1] Mailoa J. P. et al. Appl. Phys. Lett., 106 (12) 2015, p. 121105.
[2] https://taiyangnews.info/technology/33-2-efficiency-for-perovskite-silicon-tandem-cells/
[3] Futscher M. H., Ehrler B. ACS Energy Lett., 1 (4) 2016, p. 863–868.
[4] Roessler T. et al. Tandem PV Workshop, 2022.

Introduction

Interconnection with Electrically Conductive Adhesives (ECAs)

- Full-format pero-SHJ tandem modules with P_{MPP} > 430 W demonstrated in 2022, using ECA interconnection and M6 Oxford PV cells [1]
- ECAs allow processing solar cells with temperature sensitive layers [2]
- Soldering approaches of tandem cells are currently in development [3]



- ECA-based low-temperature interconnection approach of this work - shingling
- Shingling utilizes cut cells which are interconnected roof tiles-alike
- Absence of cell gaps for higher module efficiency
- Lower current density in tandem cells result in lower series resistance

[1] Roessler T. et al. Tandem PV Workshop, 2022.
[2] Geipel T. Doctoral Thesis, 2018.
[3] De Rose A. et al. Metallization and Interconnection Workshop, 2023.

Fraunhofer ISE

Simulation of the Number of Fingers and Shingle Cut Size

Modelling approach

Model predicting *I-V* parameters of perovskite-Si tandem solar cell [1-4]

Varied: number of fingers on the front side

Varied: shingle cut size

M6 format

Same number of fingers at the rear side

Same finger dimensions

Same busbar dimensions

Assumption: edges of shingles passivated[5]

[1] Shabanzadeh B. Master thesis. 2022.
[2] Fellmeth T. et al. IEEE J. Photovoltaics, 4 (1) 2014, p. 504–513.
[3] Messmer C. et al. Progress in Photovoltaics, 30 (4) 2022, p. 374–383.
[4] Schmager R. et al. Optics express, 27 (8) 2019, A507-A523.
[5] Lohmueller E. et al. Silicon PV 2023.

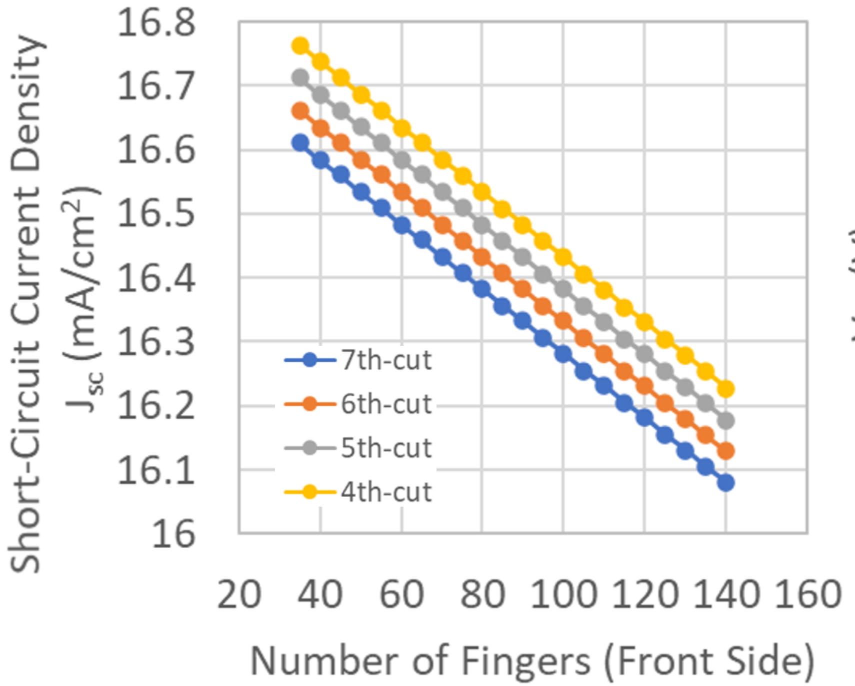
Effect of Number of Fingers on I-V Characteristics

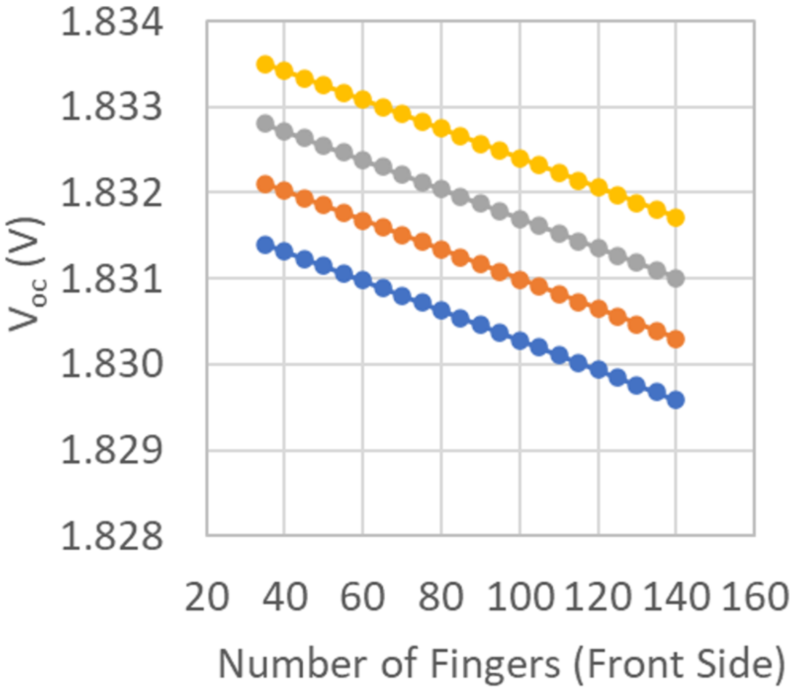
V_{OC} and J_{SC}

More fingers > lower V_{OC} and J_{SC}
Smaller cut > lower V_{OC} and J_{SC}

With increasing finger number:

- **Lower J_{SC} due to cell shading**
- **Lower V_{OC} due to increased recombination under metallization**





Fraunhofer ISE

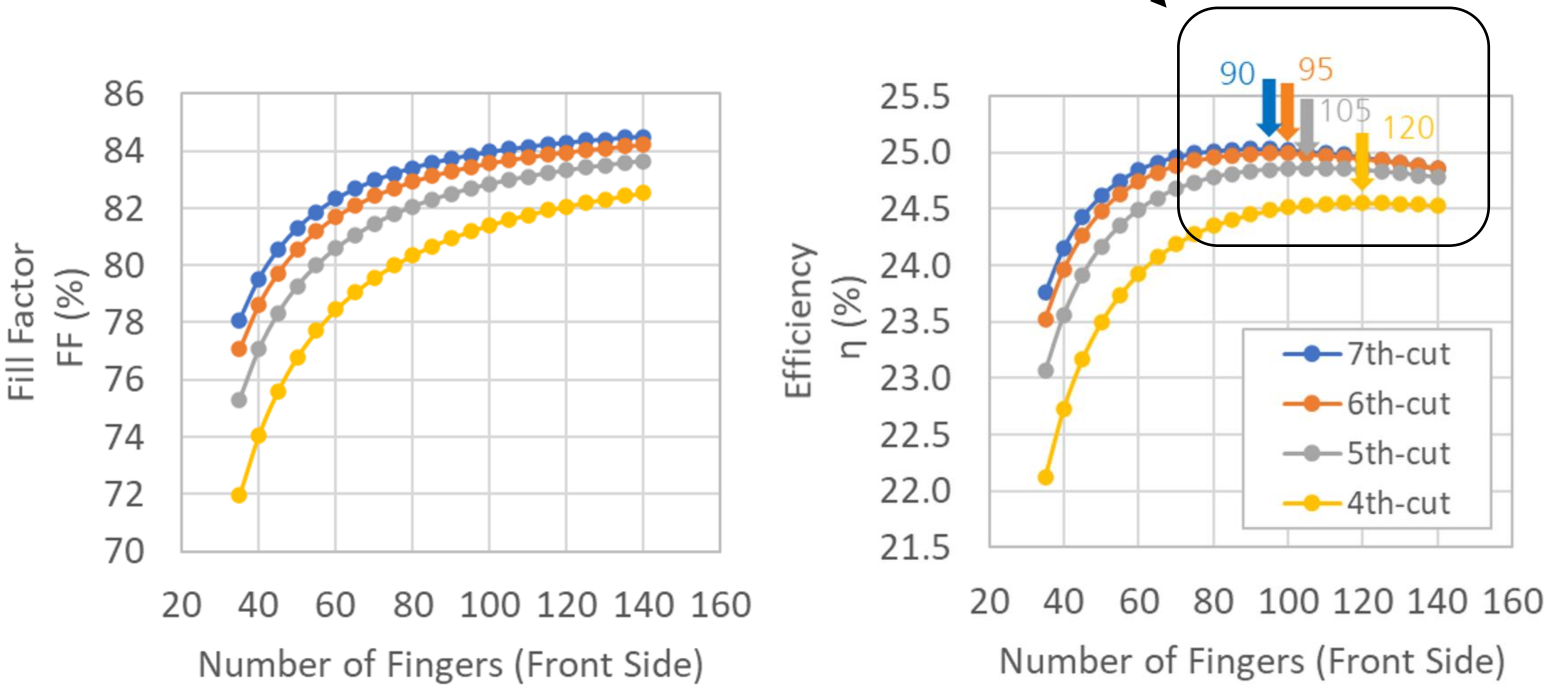
Effect of Number of Fingers on I-V Characteristics

FF and η

More fingers > less series resistance

- **Higher *FF* with more fingers due to more metallization to lead away the current**
- **Higher *FF* with smaller cut due to shorter current paths**

Optimal number of fingers for respective cut size



Cell-to-Module Analysis

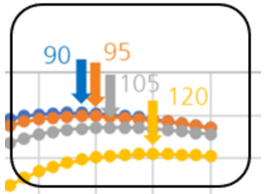
Understanding the „Waterfall Diagram“

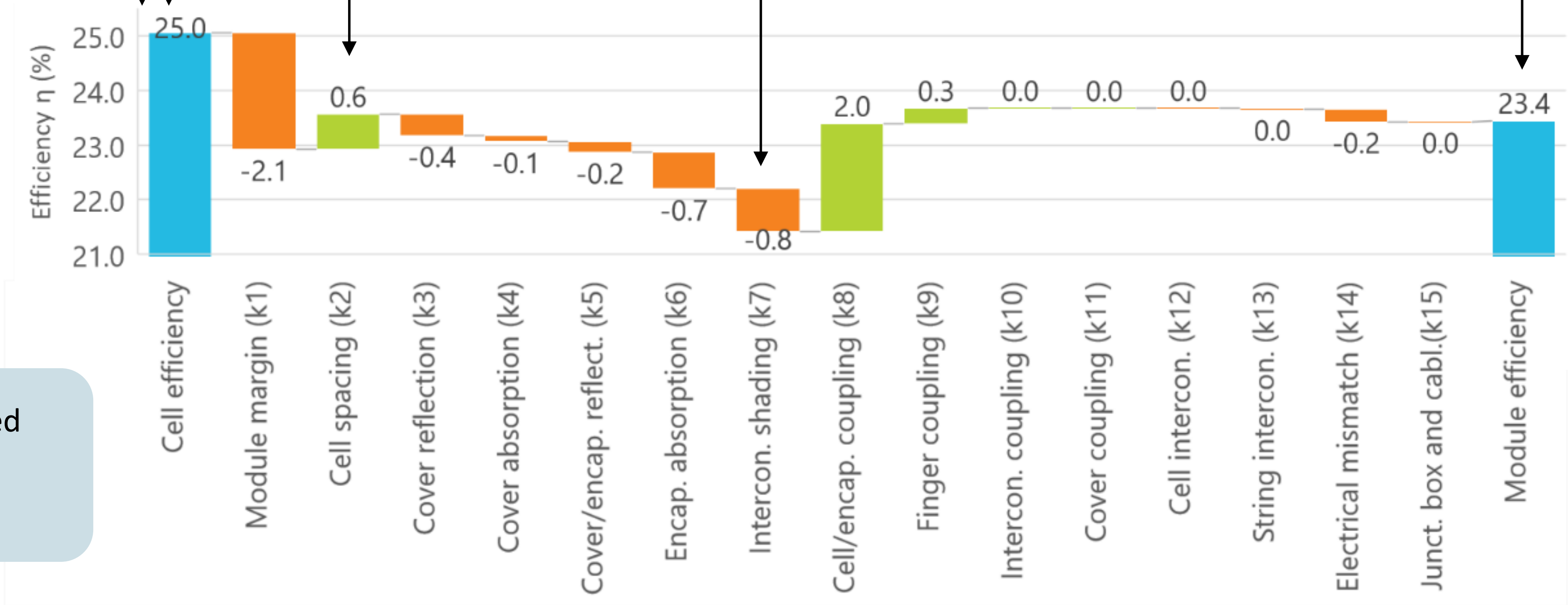
Initial efficiency: η with optimal number of fingers

Reflects the gains due to absence of cell gaps

Losses due to cell shading becuase of shingle overlap

Resulting module efficiency





I-V characteristics based on older generation tandem cell

https://www.cell-to-module.com/

Cell-to-Module Analysis

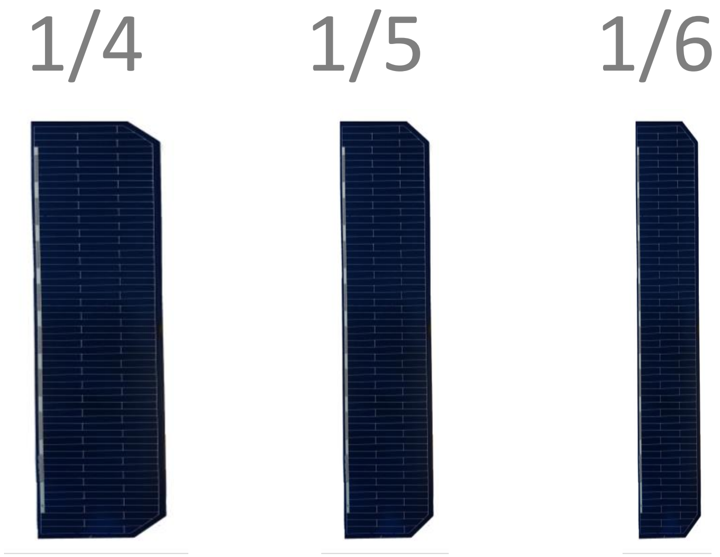
Effects of Shingle Cut Size

Input parameters for different cut sizes

- Same shingle overlap
- Same string spacing

- Similar module area (1.76 m^2 to 1.78 m^2)

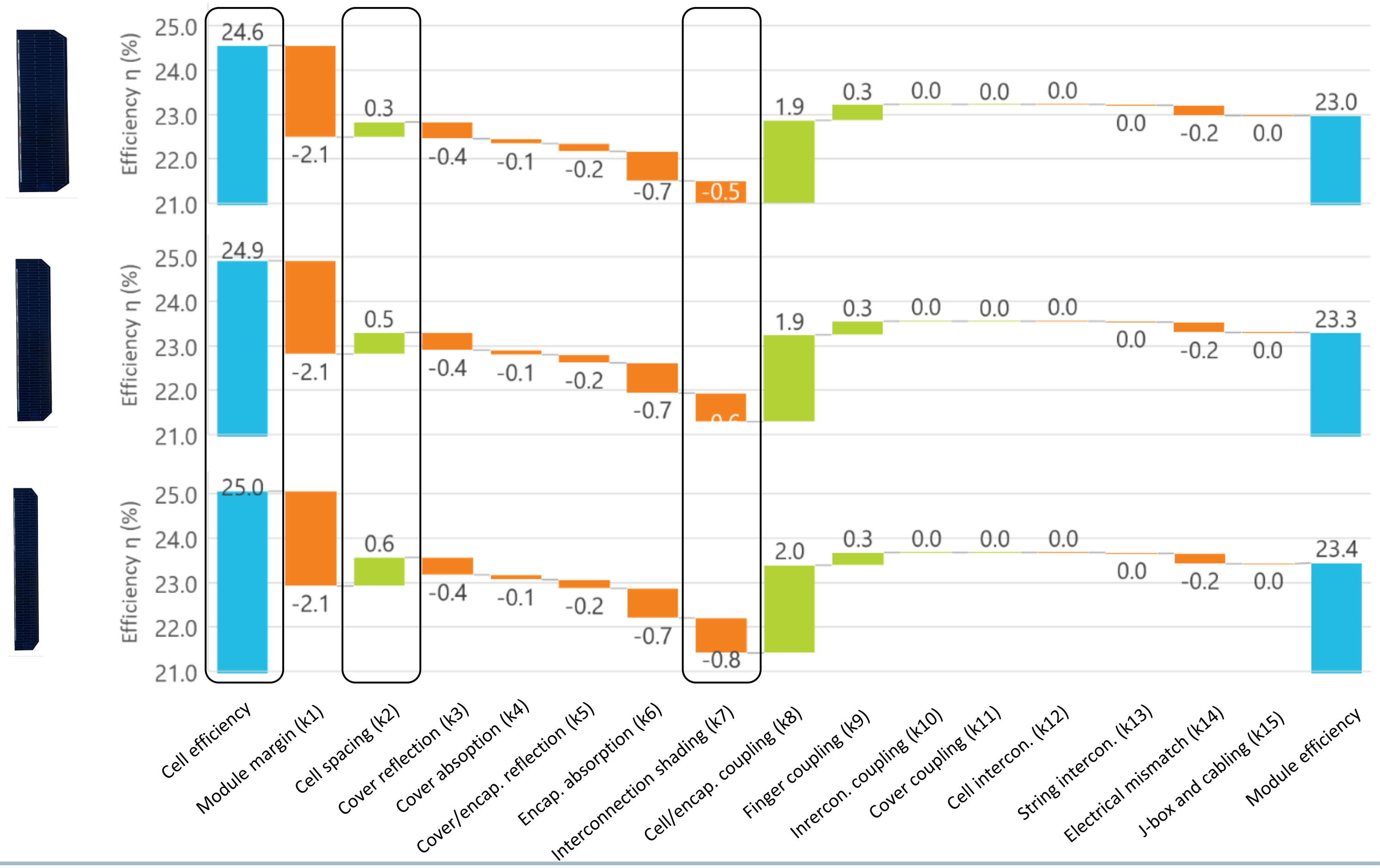
- Varying number of cells to correspond to the most similar module area



Fraunhofer ISE

Cell-to-Module Analysis

Effects of Shingle Cut Size



Using smaller shingle cut with edge passivation results in higher module efficiency due to:

- Higher initial shingle efficiency
- Optical gains due to overlap (k2+k7)

Using 1/6 cut perovskite-silicon tandem shingle cells with 25% efficiency would result in a module with η = 23.4%

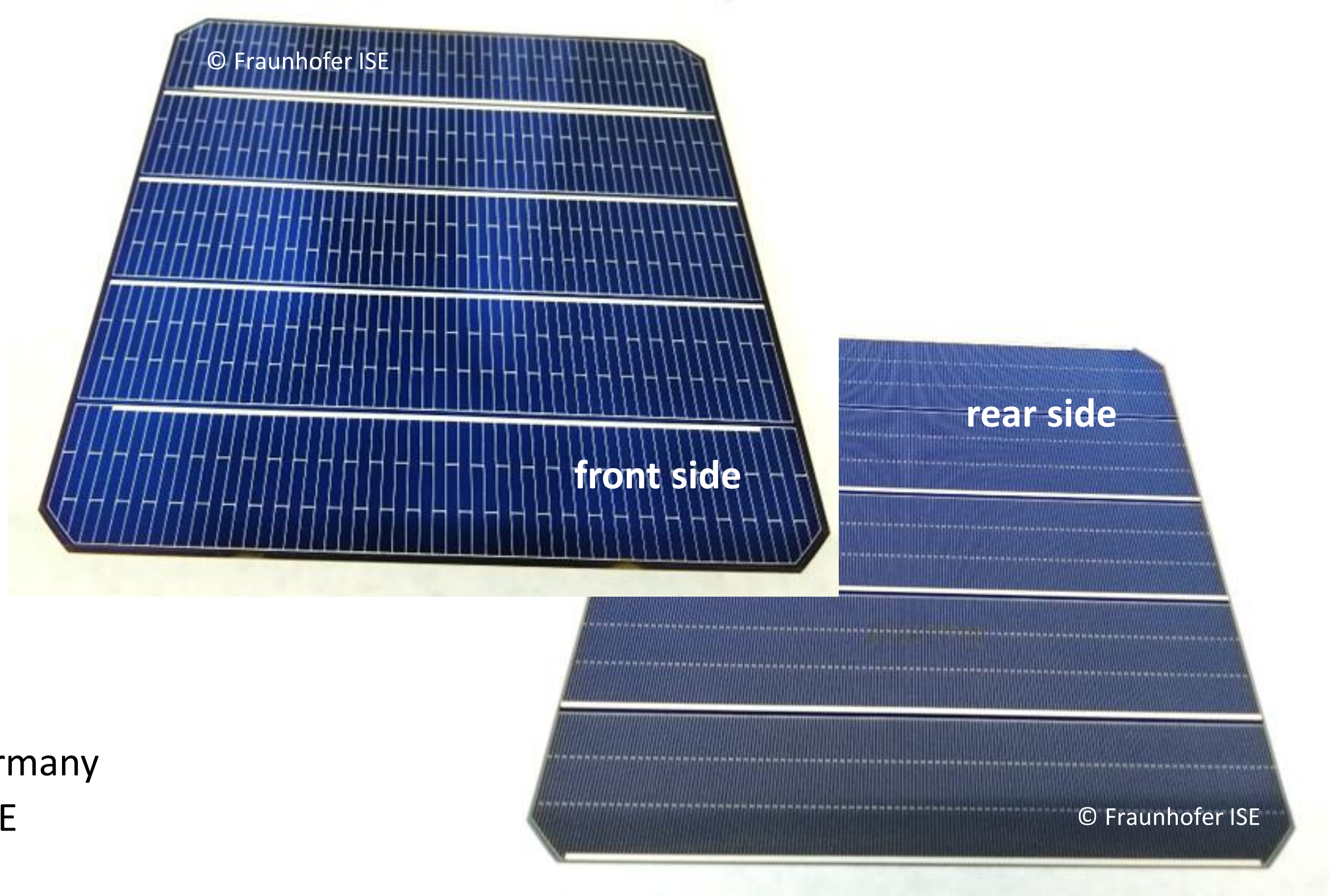
https://www.cell-to-module.com/

Fraunhofer ISE

Perovskite-Si Tandem Shingle Module Prototype

Approach

- Tandem wafers were provided by Oxford PV Germany
  - M6 format (166 mm × 166 mm)
- Metallization at Fraunhofer ISE
  - Automatic screen printing process
  - Low-temperature silver paste
- Cutting into shingles with LSMC process at Oxford PV Germany
- Interconnection and module integration at Fraunhofer ISE



Fraunhofer ISE

Perovskite-Si Tandem Shingle Module Prototype

Interconnection

- Automatic interconnection on TT1600 ECA stringer
- 18 mg ECA per wafer
- Interconnection with commercially available ECA with high throughput
- ECA application with screen printing

Fraunhofer ISE

Perovskite-Si Tandem Shingle Module Prototype

Encapsulation

- Conventional I_{SC} and V_{OC} output parameters
  - 28 shingles per string
  - 10 strings in parallel

- 2 diodes per module
- More diodes by change of module layout easily possible

- Lamination on industrial machine
- Glass-glass design
- Polyolefin encapsulation material
- Butyl edge sealant for additional humidity barrier

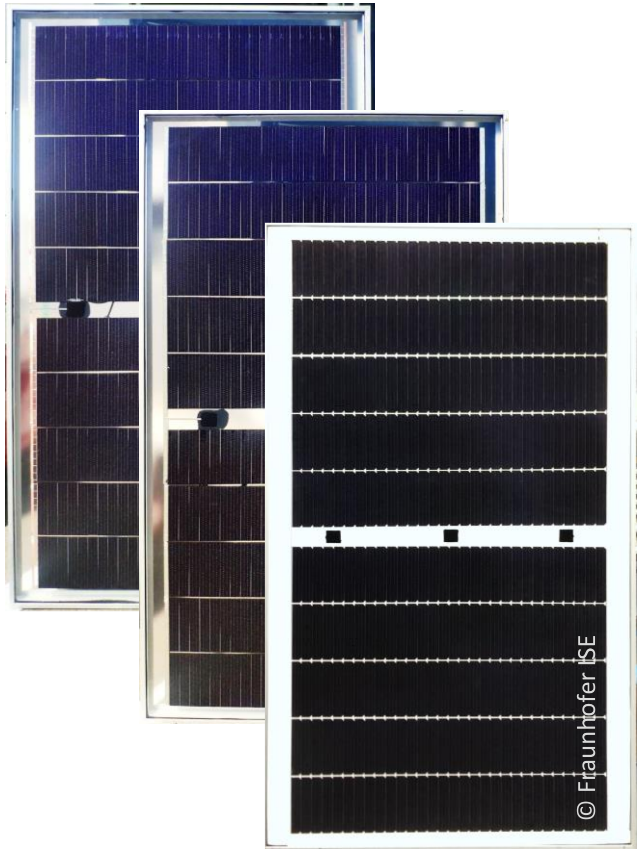
Perovskite-Si Tandem Shingle Module Prototypes

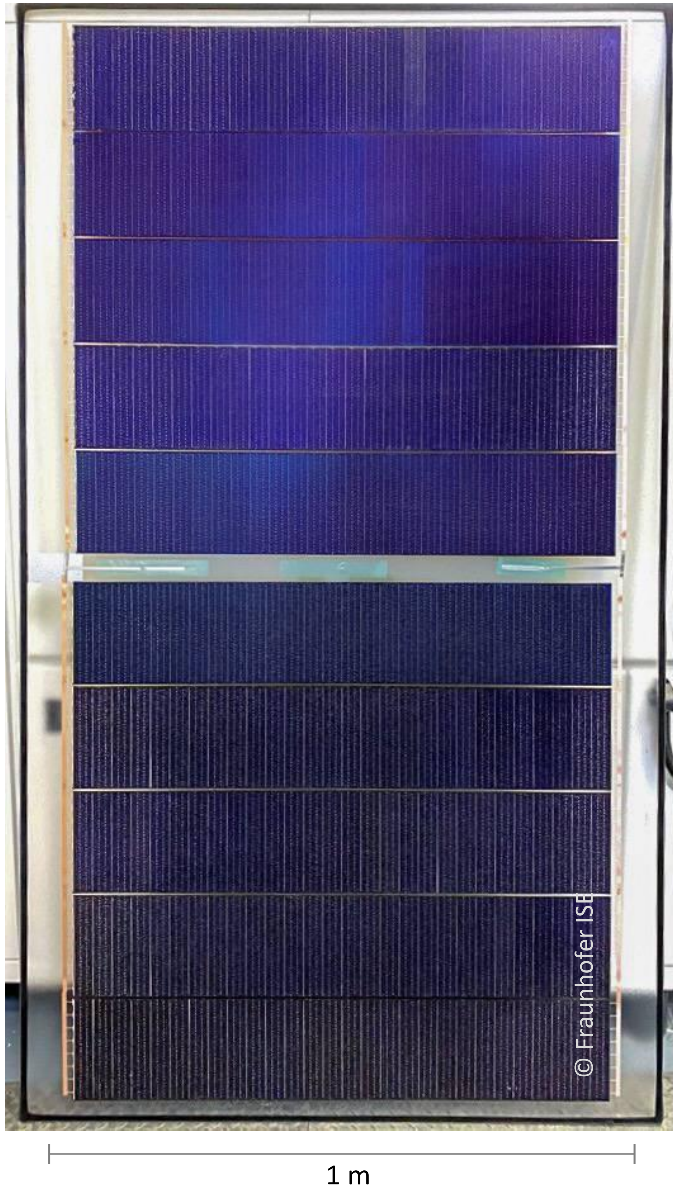
Full-Format Shingle Perovskite-Si Tandem Modules

Successful prototype production of several full-format shingled tandem modules

- Module aperture area 1.5 m^2
- Highest achieved module efficiency $22.7\%_{ap.}$

Production of full-format shingle modules with perovskite-Si tandem cells is possible with industrial equipment and materials





Fraunhofer ISE

Shingling Meets Perovskite-Silicon Heterojunction Tandem Solar Cells

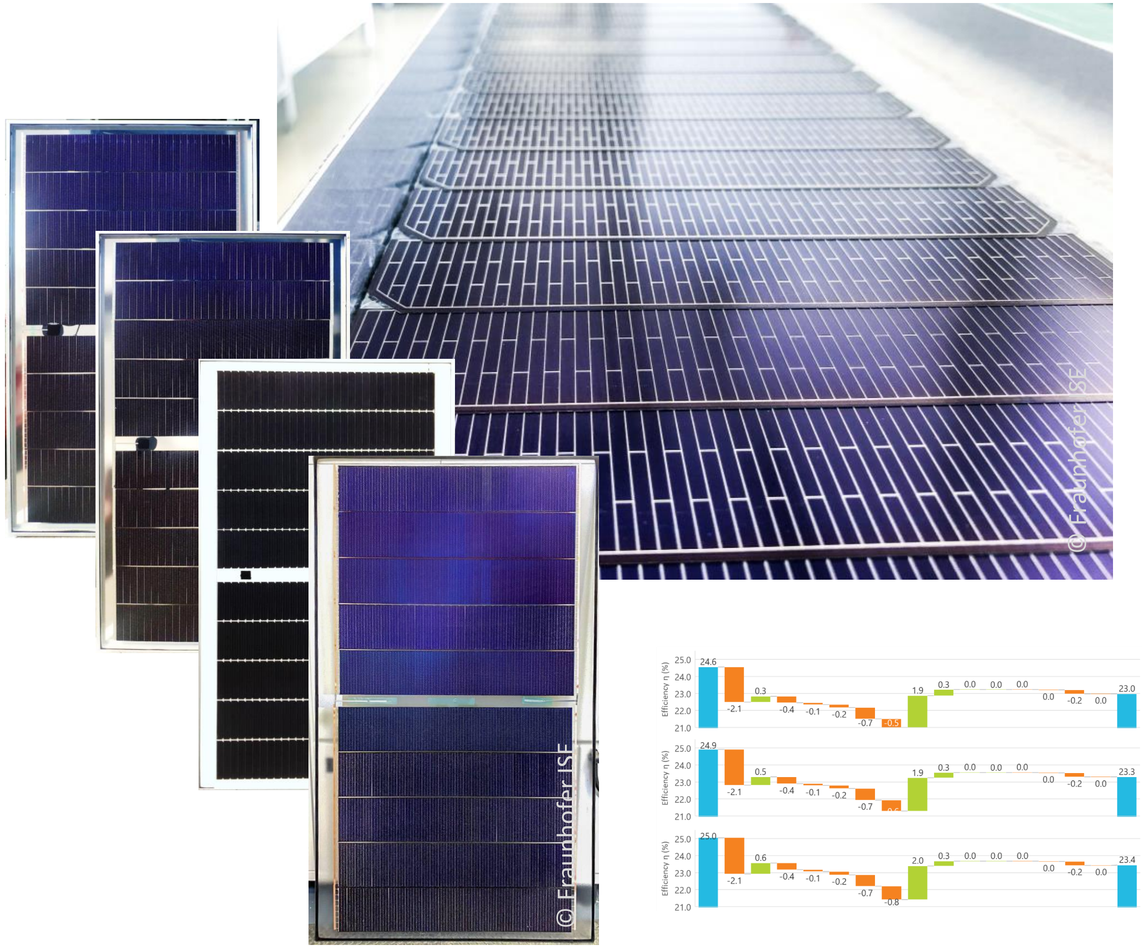
Summary

1. Number of fingers and shingle cut size simulated
   - 1/7 cut with 90 fingers is optimum with passivated edges

2. 25% efficiency tandem shingles would predict to result in a module with η = 23.4%

3. Prototype full-format perovskite-Si shingle modules with η up to $22.7\%_{ap.}$ produced

4. Shingling is ready for tandem



Fraunhofer
ISE

Thank you for your attention!

Veronika Nikitina
Interconnection Technology | Photovoltaic Modules
veronika.nikitina@ise.fraunhofer.de

Fraunhofer ISE
Heidenhofstraße 2
79110 Freiburg
www.ise.fraunhofer.de

This work has been funded by the Federal Ministry for Economic Affairs and Climate Action within the project "SWiTch" (contract no. 03EE1067C)

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag