TOPCon Silicon Solar Cells

From Lab to Fab

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J. Rentsch, M. Hermle, R. Preu

Fraunhofer Institute for Solar Energy Systems ISE
Freiburg, Germany

PV Magazine Webinar
17. Feb 2022

Fraunhofer ISE

TOPCon
From Lab to Fab

- Development of Record Efficiencies for Both-sides Contacted Solar Cells
- TOPCon Structure and Principle
- n-type and p-type TOPCon Cells
- i-TOPCon and Costs

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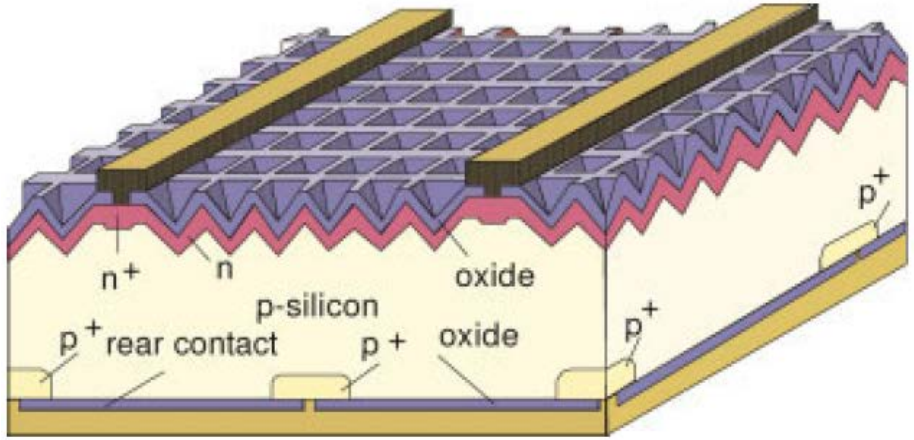
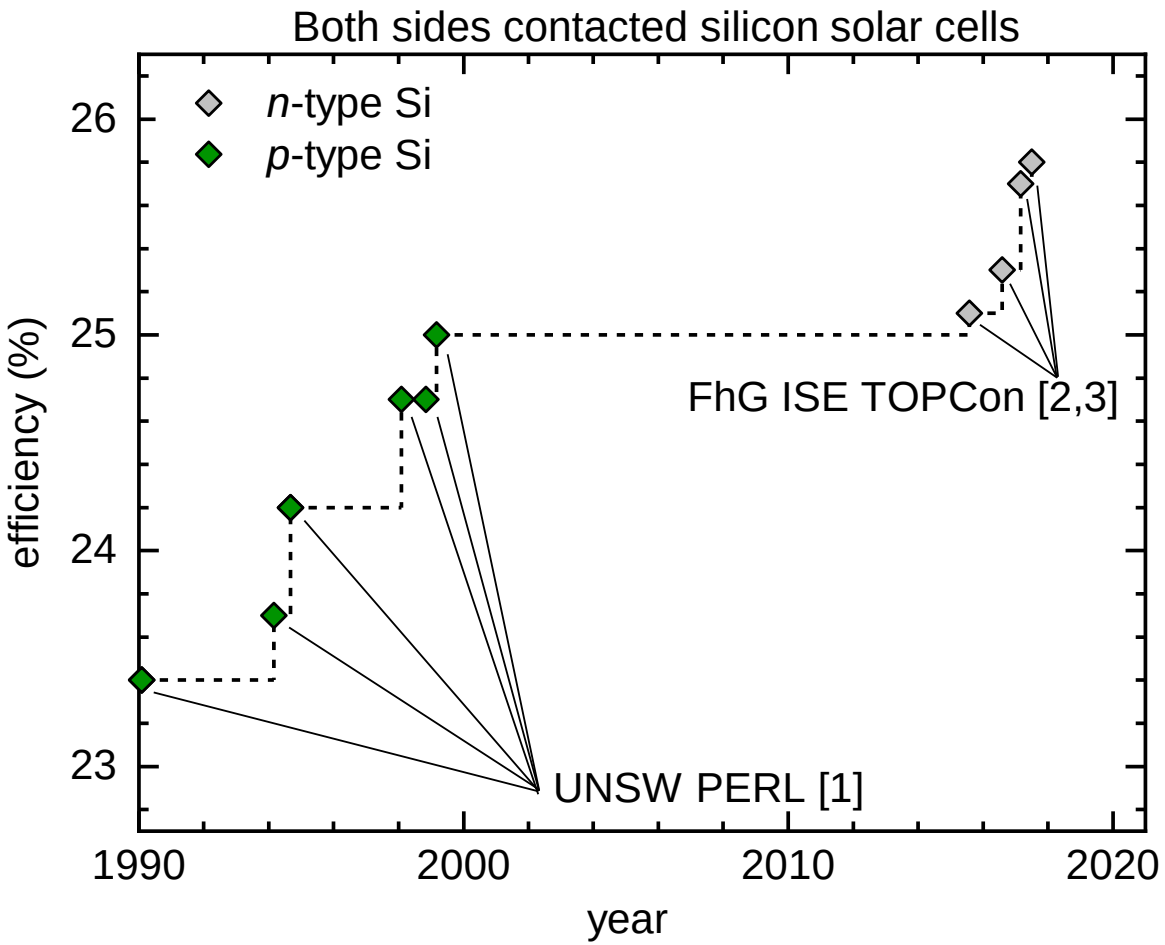
Modern History of Record Silicon Solar Cells with Front and Rear Contacts

TOPCon – Main Driver for Recent Efficiency Boost

- Records in the 90s dominated by strong improvements in PERL cells at UNSW (Passivated Emitter and Rear Locally diffused)





History of Record Silicon Solar Cells with Front and Rear Contacts

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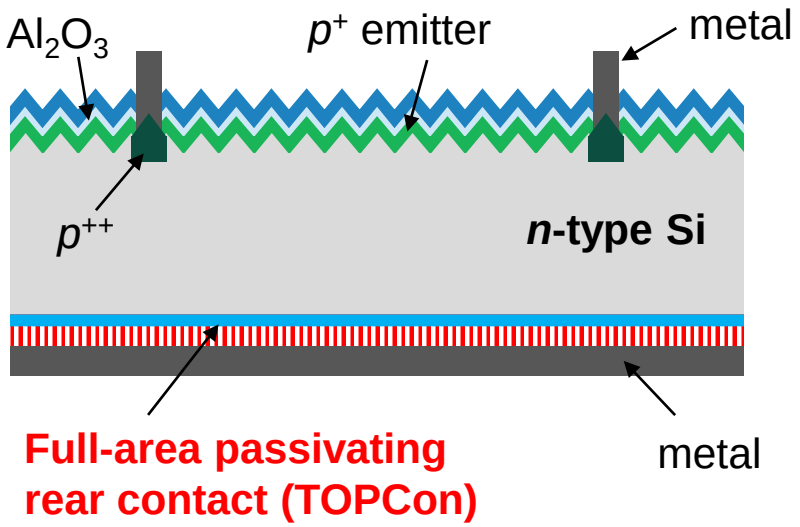
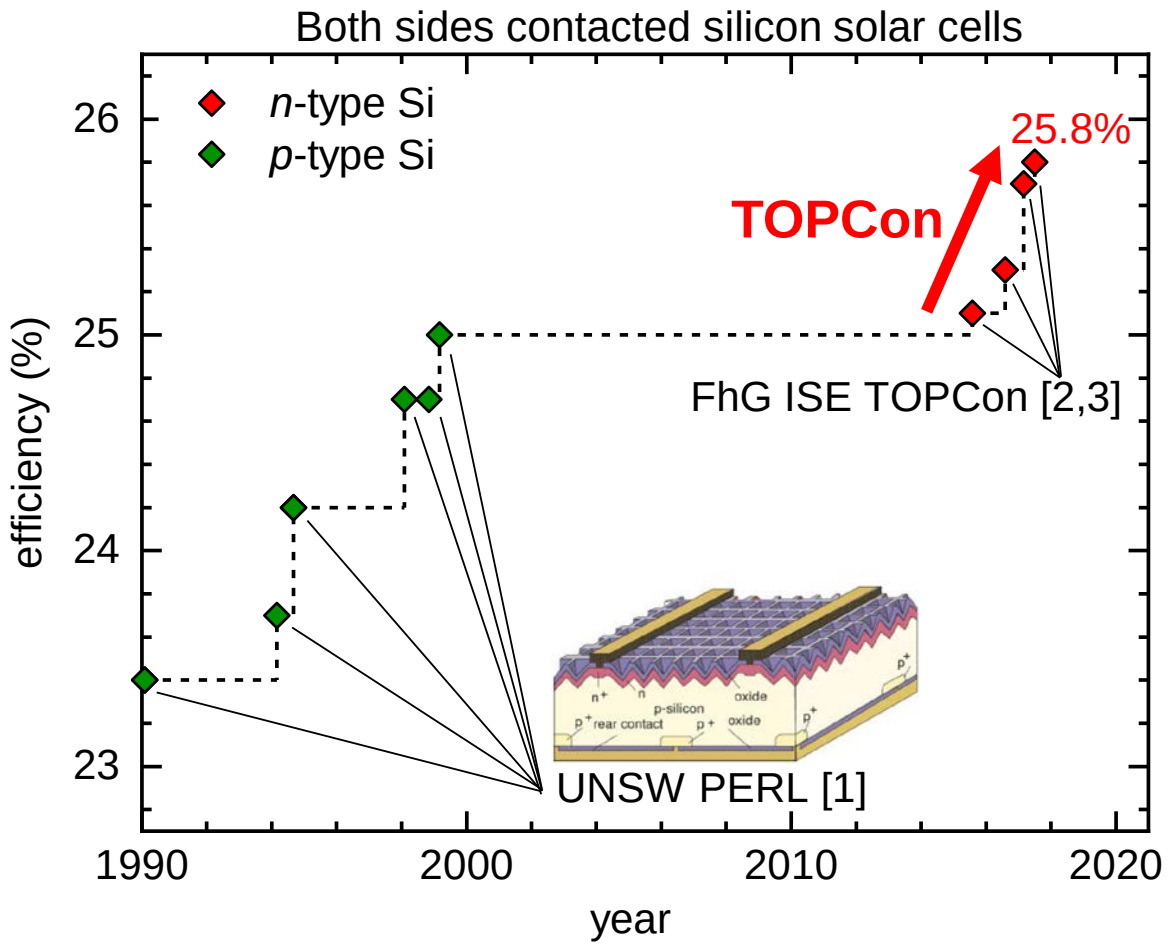
- Progress in past few years with ***n*-type silicon solar** cells featuring **passivating contacts**





S. Glunz, 2022

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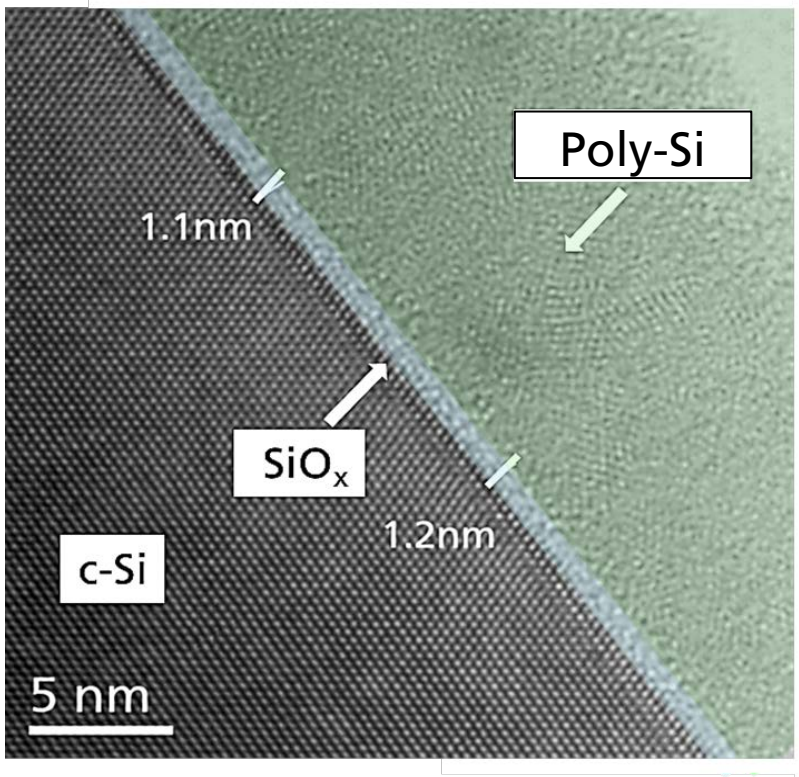


TOPCon – A Passivating Contacts Technology Based on Poly-Silicon Thin Films

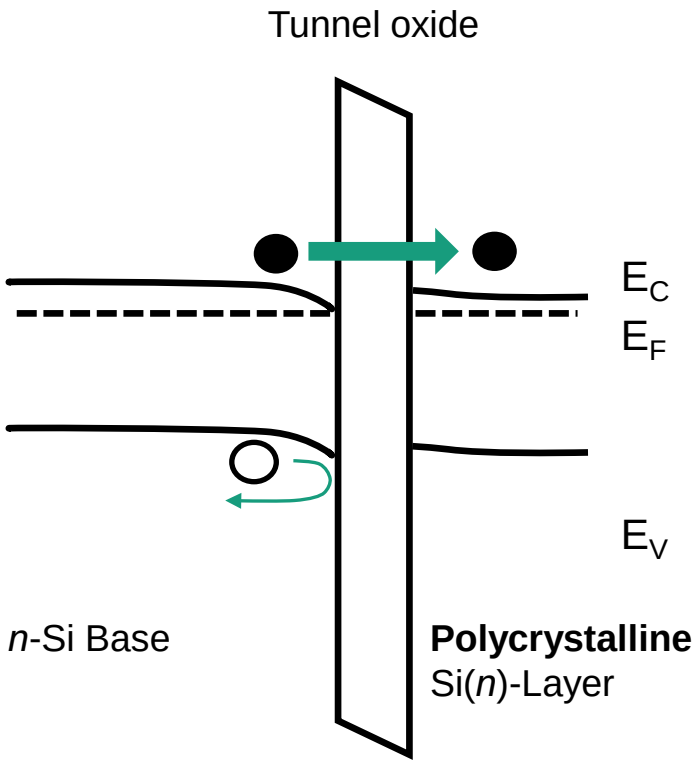
Brief Review

TOPCon – Tunnel Oxide Passivating Contact

Silicon oxide growth
Interface Passivation

Doped a-Si layer deposition
Carrier Selectivity

High-temperature anneal
Crystallization, dopant activation



Feldmann, Bivour, Reichel, Hermle, Glunz, "Passivated rear contacts for high-efficiency n-type Si solar cells providing high interface passivation quality and excellent transport characteristics", SolMat (2014)

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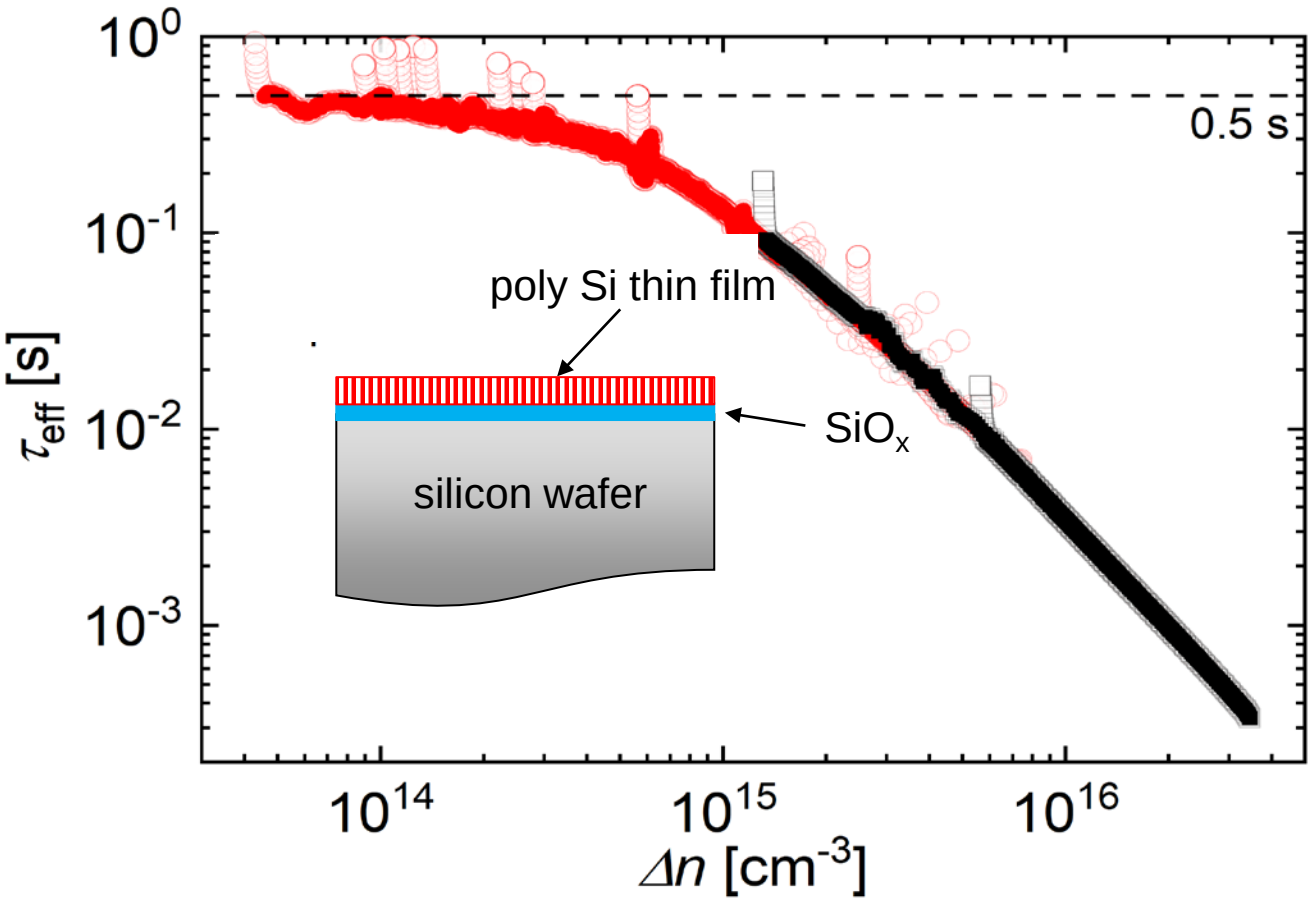
Crystallization, dopant activation

Hydrogenation
Interface passivation

- Outstanding surface passivation combined with very effective current transport



Glunz *et al.*, "Silicon-based passivating contacts: The TOPCon route", Prog Photovolt. (2021)
Graph adapted from Steinhauser *et al.*, Solar RRL (2021)

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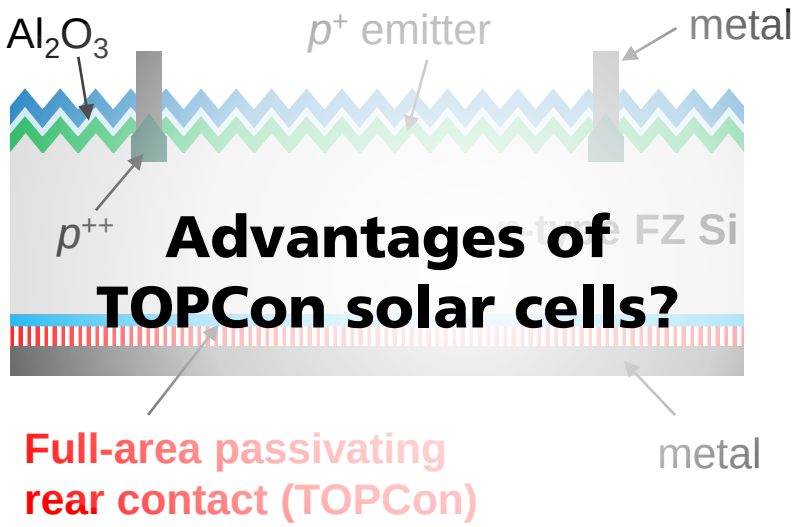
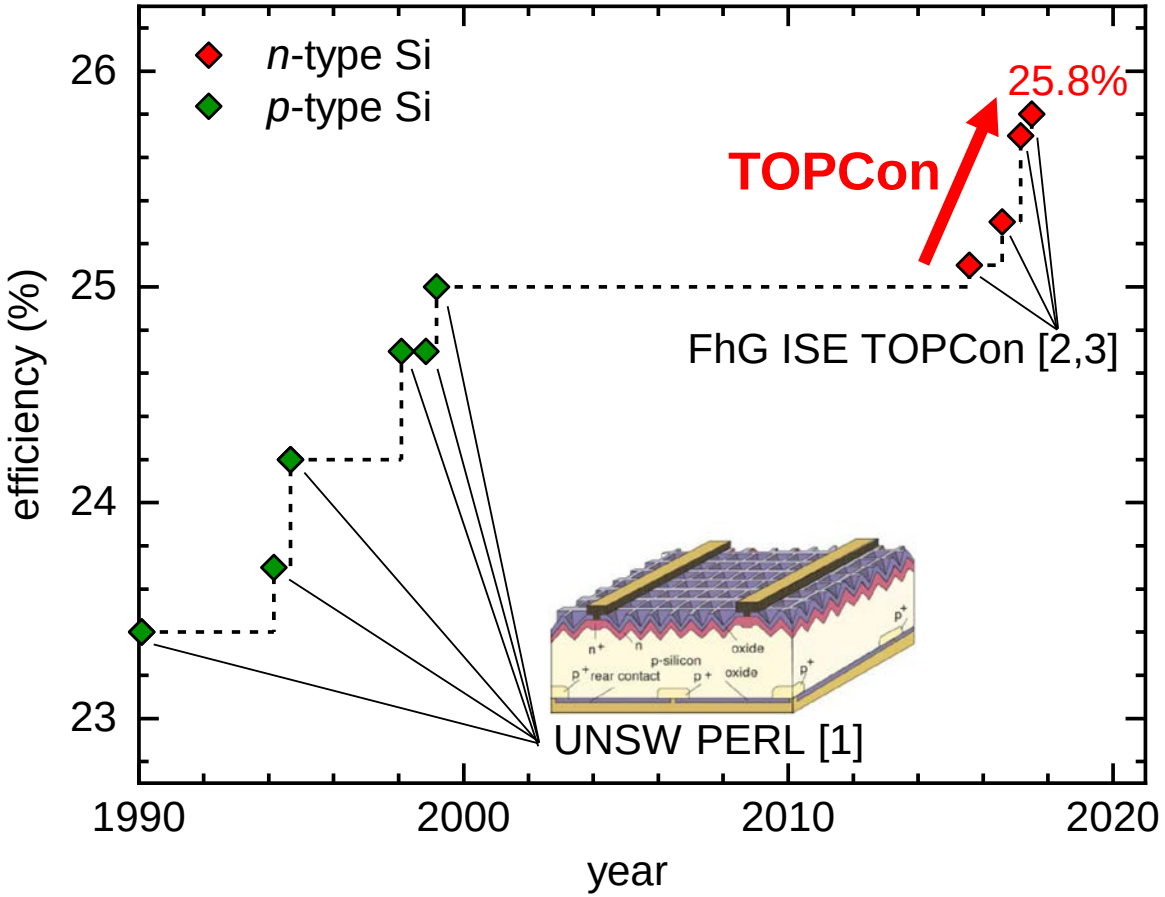
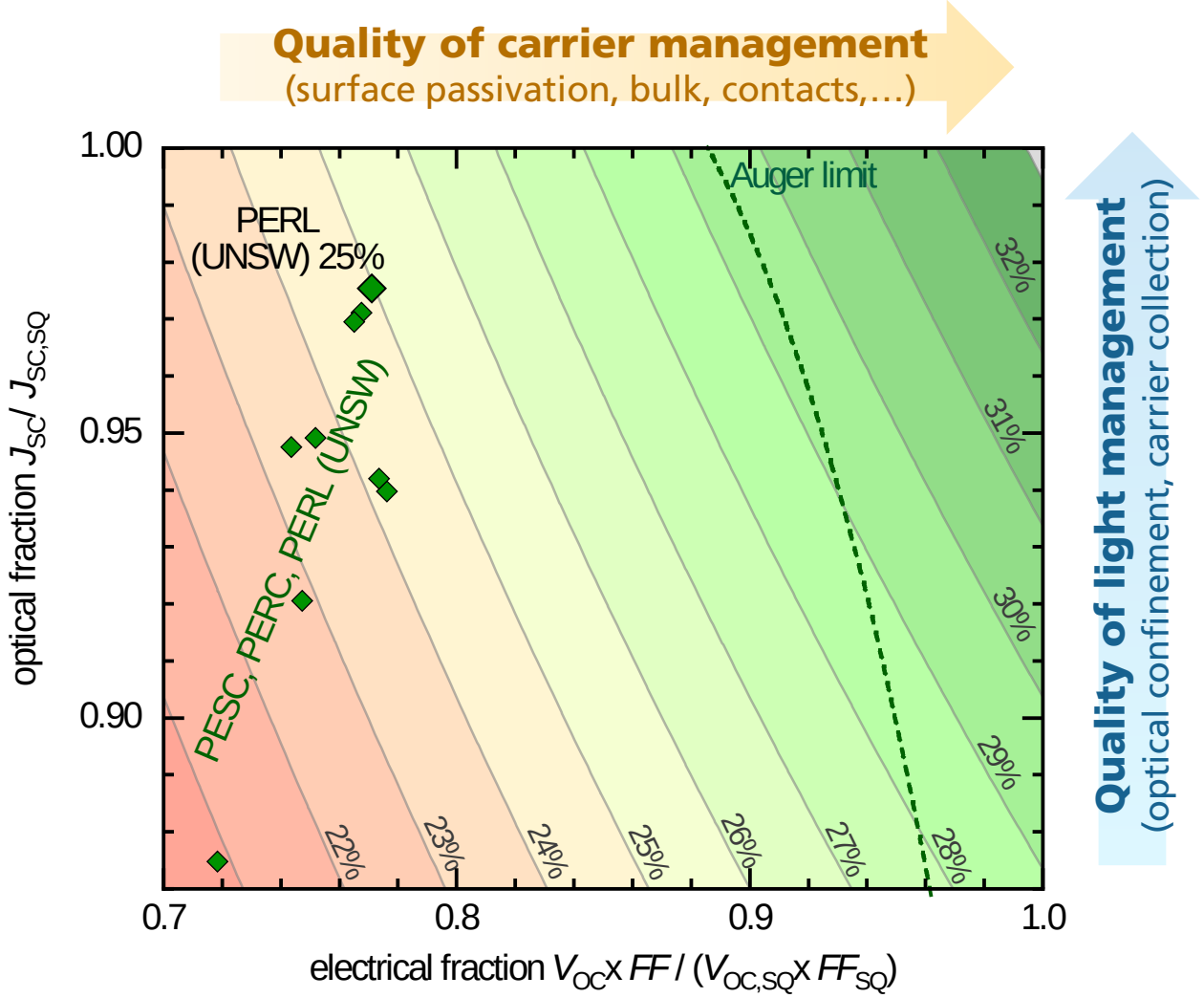




Modern History of Record Silicon Solar Cells with Front and Rear Contacts

Optical and Electrical Performance of Different Cell Technologies

- I-V parameters normalized to Shockley-Queisser (SQ) limit for quality characteristics:
  - Light management
  - Carrier management
- **UNSW cell designs** with diffused junction
  High optical and electrical performance



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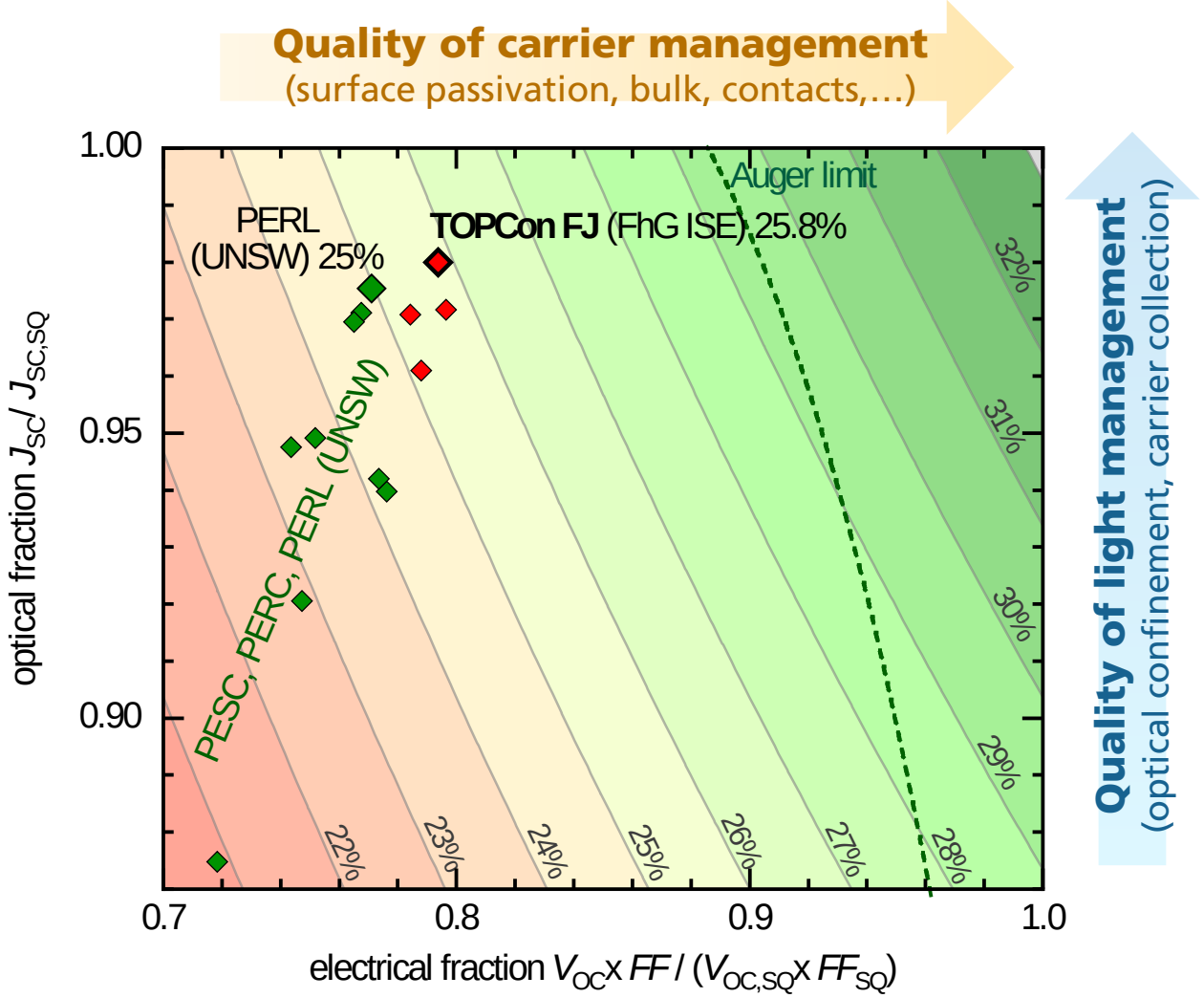

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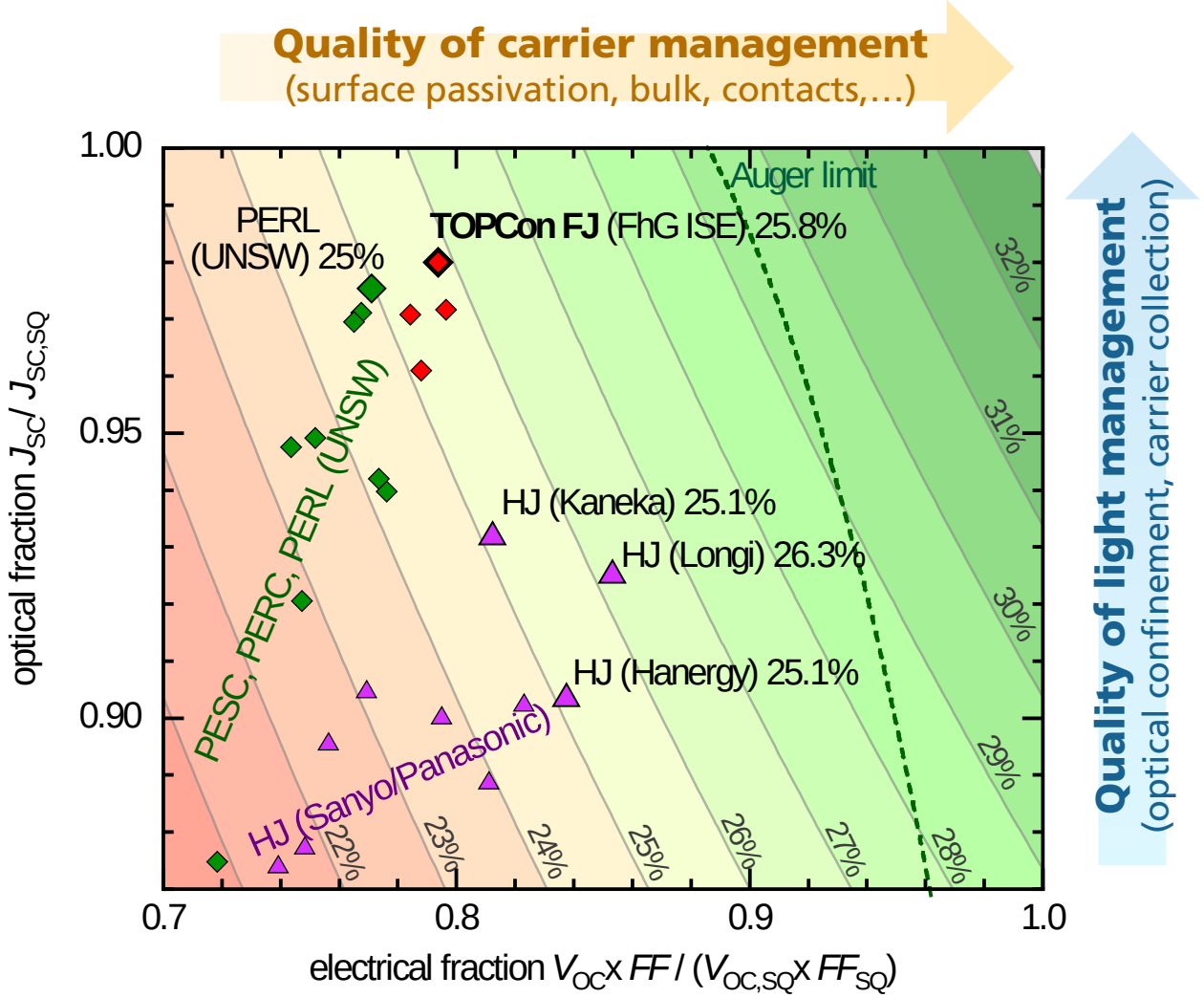
- **TOPCon cells** combine high optical with higher electrical performance
- **Amorphous Si heterojunction (HJ) cells** superior electrical performance, but lower optical performance



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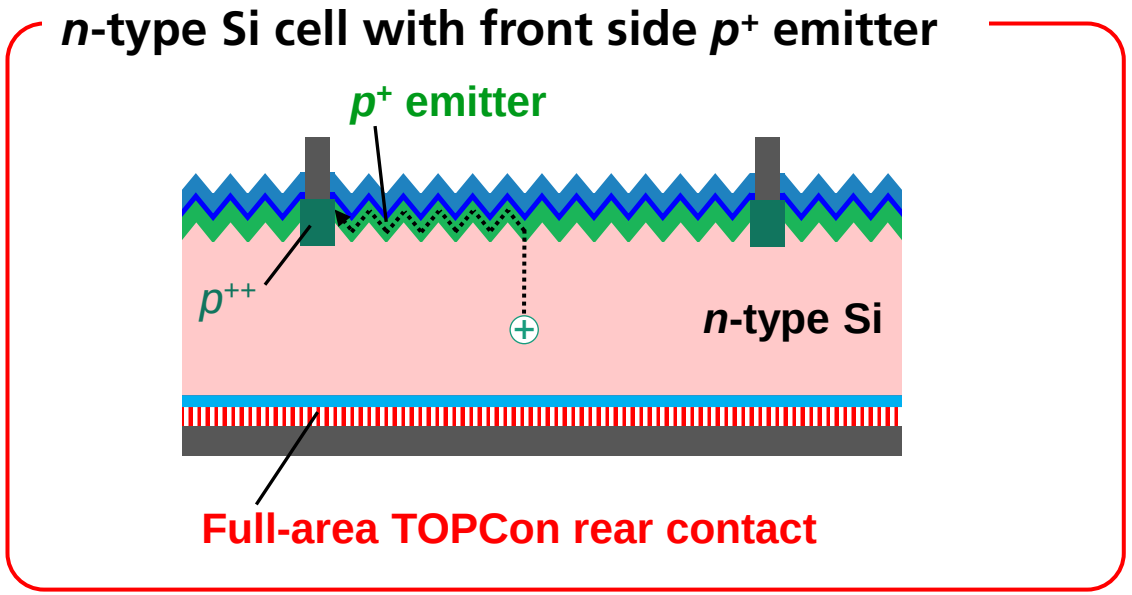
Change From Front Junction to Back Junction Cell Architecture
Optimization from a Current Transport Point of View



- Lateral hole transport mainly through p^+ emitter

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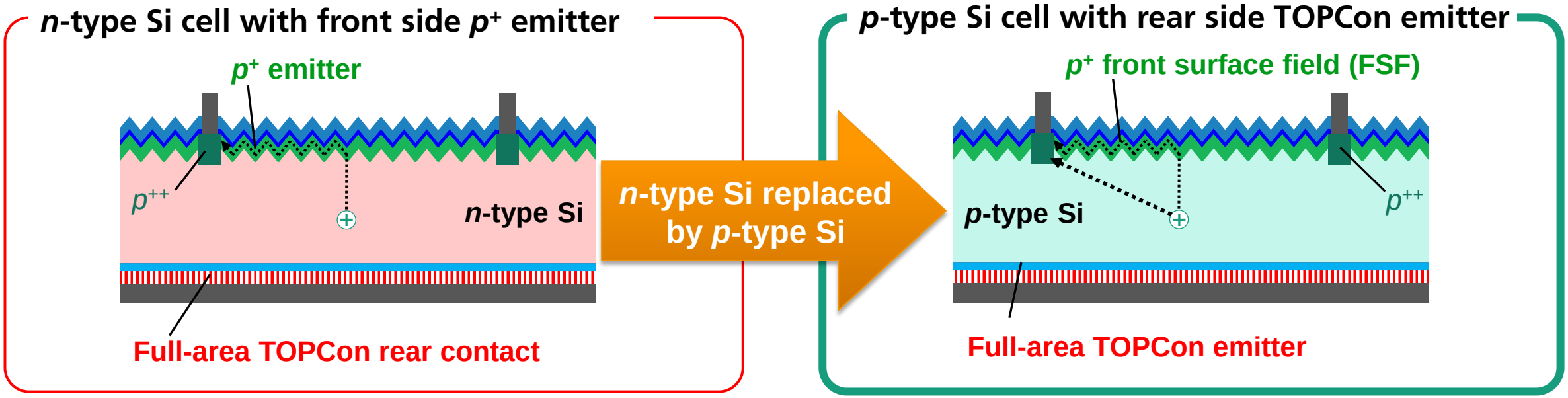


- Lateral hole transport mainly through p^+ emitter

- Lateral hole transport through p^+ FSF **and *p*-type Si base** [2]
- More relaxed requirements for FSF sheet resistance

Richter *et al.*, "Design rules for high-efficiency both-sides-contacted silicon solar cells with balanced charge carrier transport and recombination losses", Nature Energy (2021)

Front Junction vs Rear Junction Cell Design

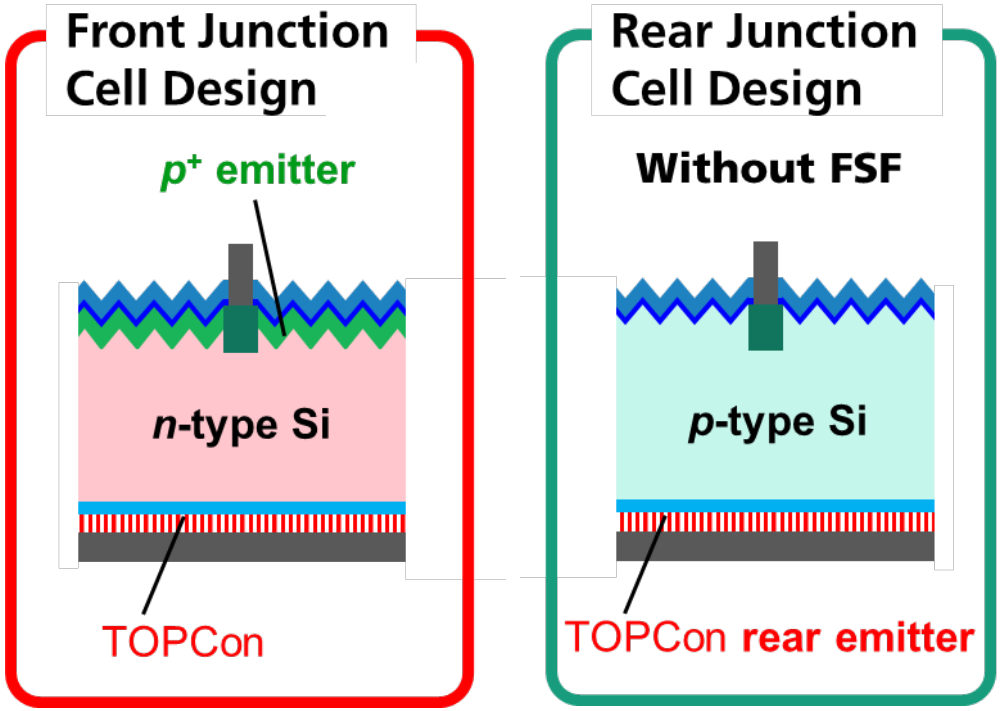
Experimental Solar Cell Results

- Experimental fabrication of *p*-type rear junction cells without front surface field (FSF)

- IV results of champion lab cell compared to best *n*-type front junction cell:

Design	V_{oc} (mV)	*FF* (%)
Front junction	724	83.1
Rear junction without FSF	**732**	**84.3**

Certified by Fraunhofer ISE CalLab, designated area: 2x2 cm²



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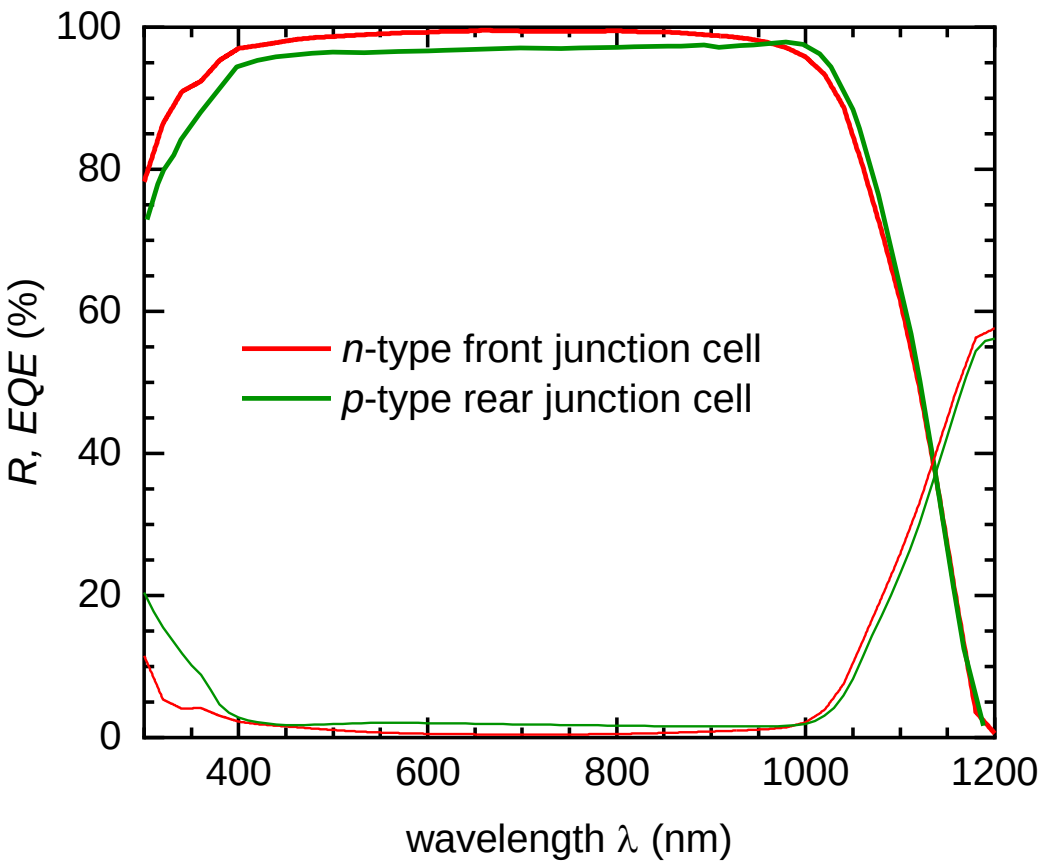

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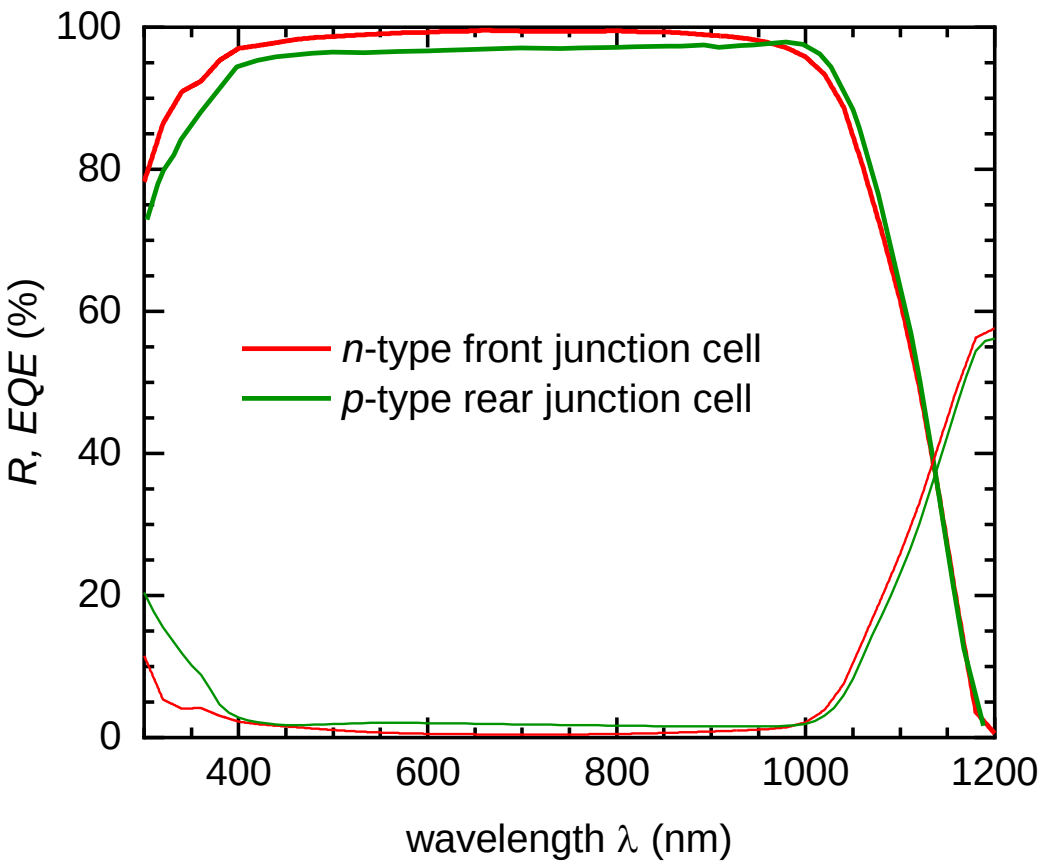
- ***Both sides contacted silicon solar cell with 26% efficiency***



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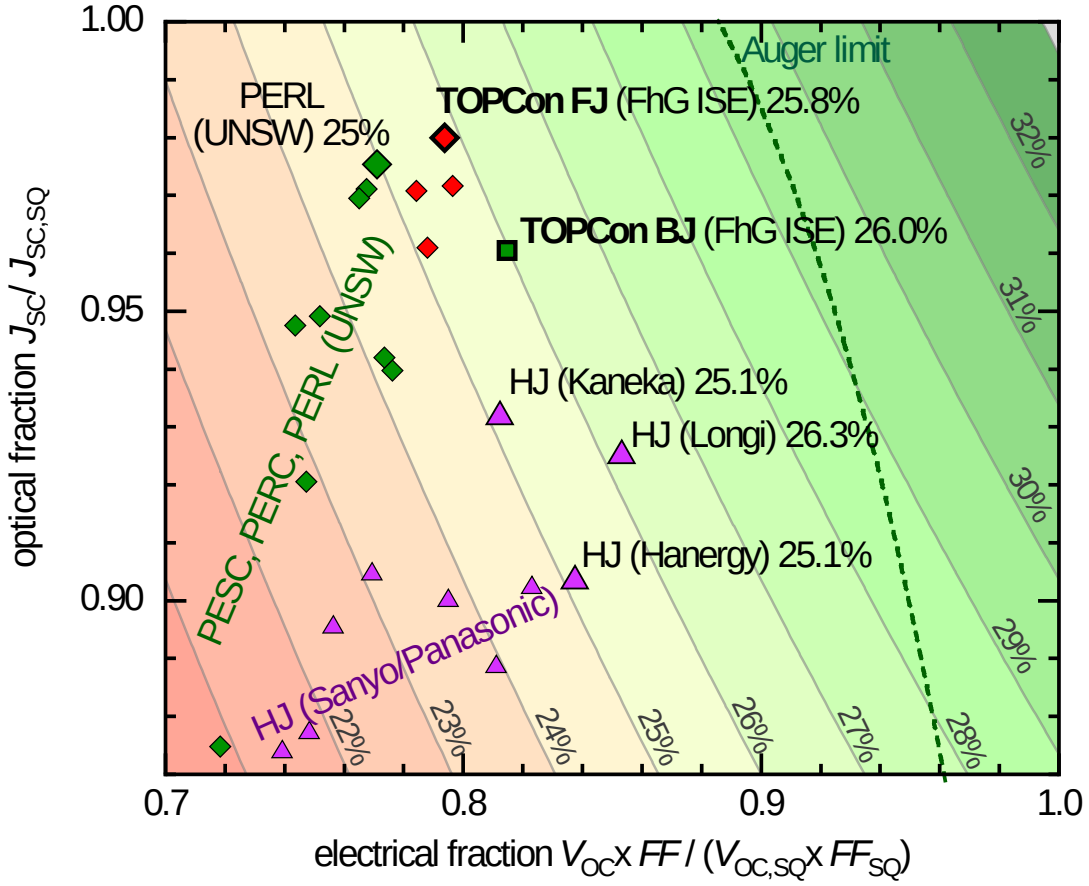

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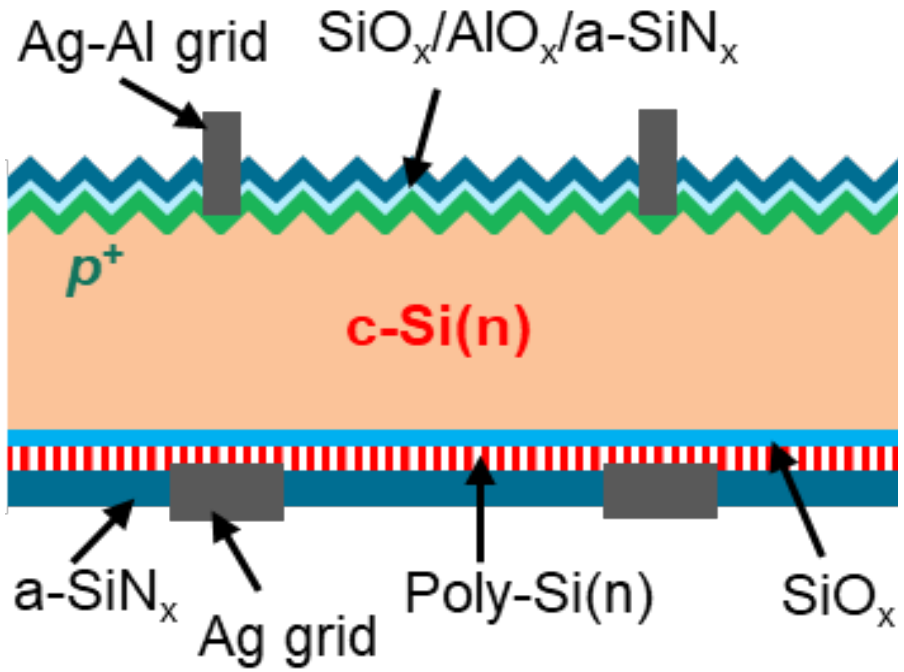


Choice of Process Technologies

PERC 2014 – TOPCon today

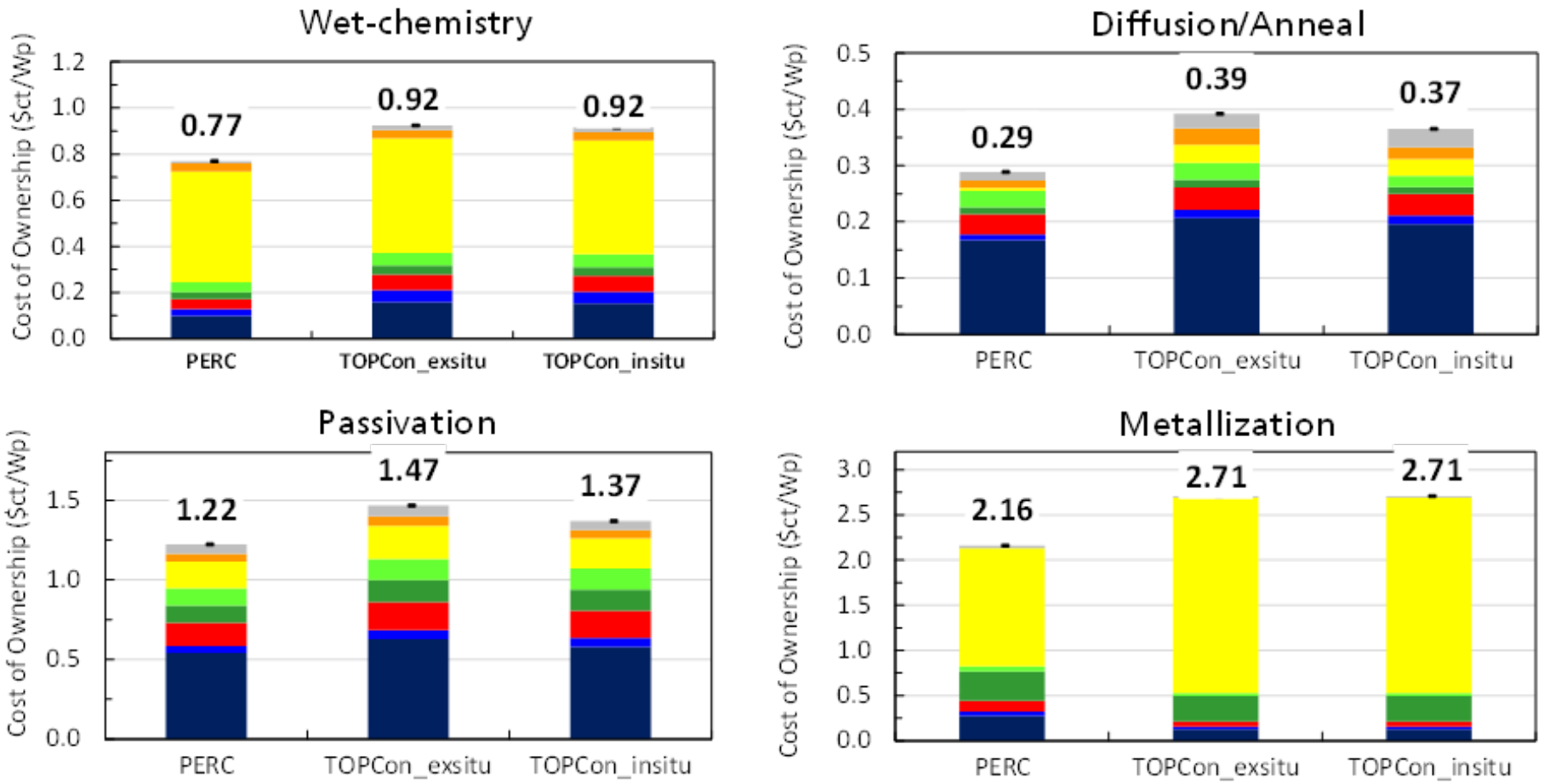
	Substrate	Thin oxide	Polysilicon	Metallization	Others
TOPCon	▪ p-type ▪ n-type	▪ Wet-chemical ▪ UV ▪ Thermal ▪ Plasma	▪ PECVD ▪ LPCVD ▪ PVD ▪ PEALD ▪ APCVD ▪ in-situ doping ▪ ex-situ doping ▪ Annealing	▪ Evaporation ▪ Screen-printing ▪ Plating ▪ TCO	▪ Cell structure ▪ Process flow ▪ Ind. maturity ▪ Yield ▪ Cost
PERC in 2014	▪ p-type ▪ LID	▪ AlO_x:H ▪ Thermal SiO_2 ▪ SiN_xN_y:H ▪ SiN_x:H capping	▪ ALD ▪ PECVD ▪ PVD	▪ LFC ▪ Laser/chem. opening ▪ Evaporation ▪ Screen-printing	▪ Cell structure ▪ Process flow ▪ Ind. maturity ▪ Yield ▪ Cost

Glunz *et al.*, "Silicon-based passivating contacts: The TOPCon route", Prog Photovolt. (2021)
Graph adapted from Chen *et al.*, EU-PVSEC (2019)

Cost of ownership
PERC vs TOPCon

Increase of COO due to

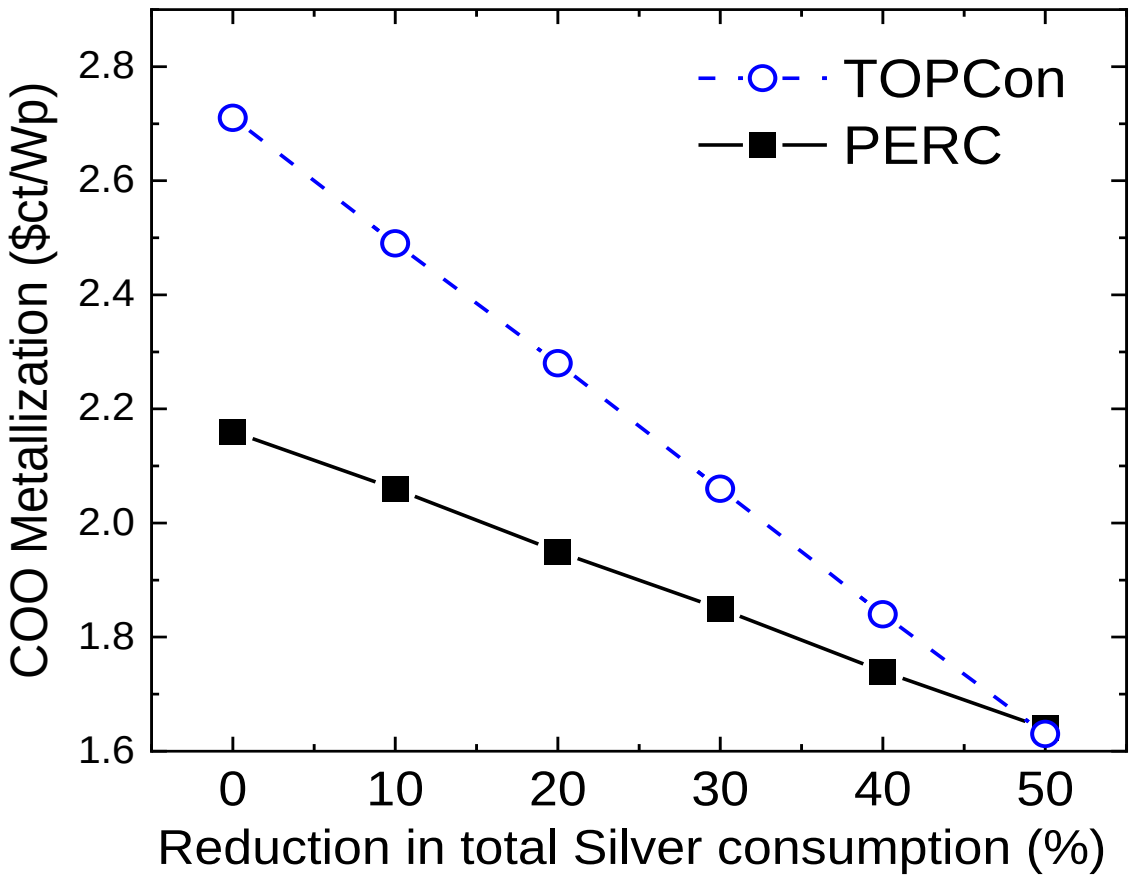
- poly-Si deposition
- Chemical edge isolation
- Ag metallization on both sides



Kafle *et al.*, "TOPCon – Technology options for cost efficient industrial manufacturing", SolMat (2021)

Cost of ownership - PERC vs TOPCon
Metallization

- Silver consumption has to be reduced (for TOPCon even more than for PERC)
- Ni/Cu Plating as an alternative



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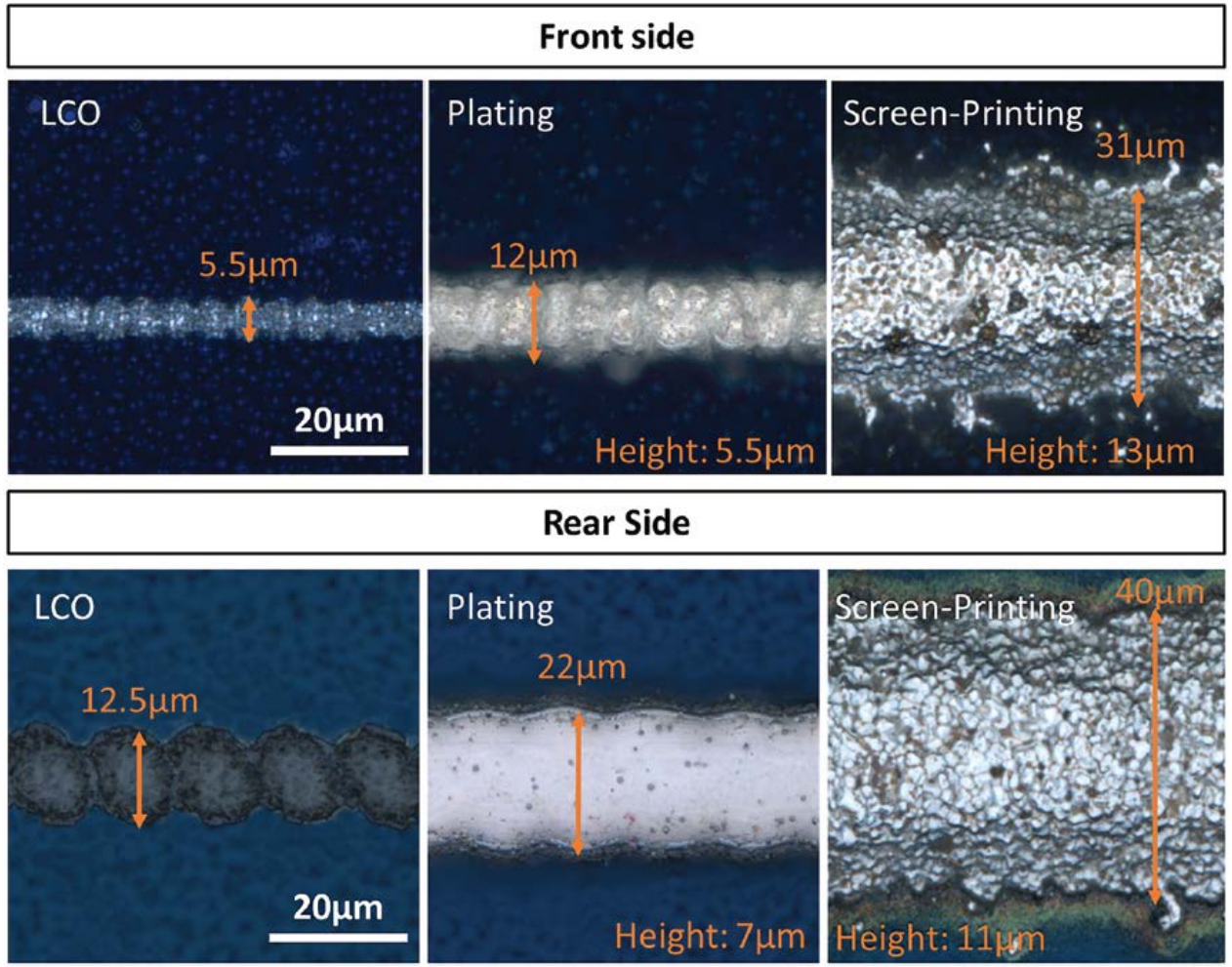
Cost of ownership - PERC vs TOPCon
Metallization

- Silver consumption has to be reduced (for TOPCon even more than for PERC)
- Ni/Cu-Plating as an alternative
- Thinner poly-Si layer possible
- New result at Fraunhofer ISE on industrial TOPCon precursors
  - Screen-printing **23.46%**
  - Cu-Plating: **23.84%**

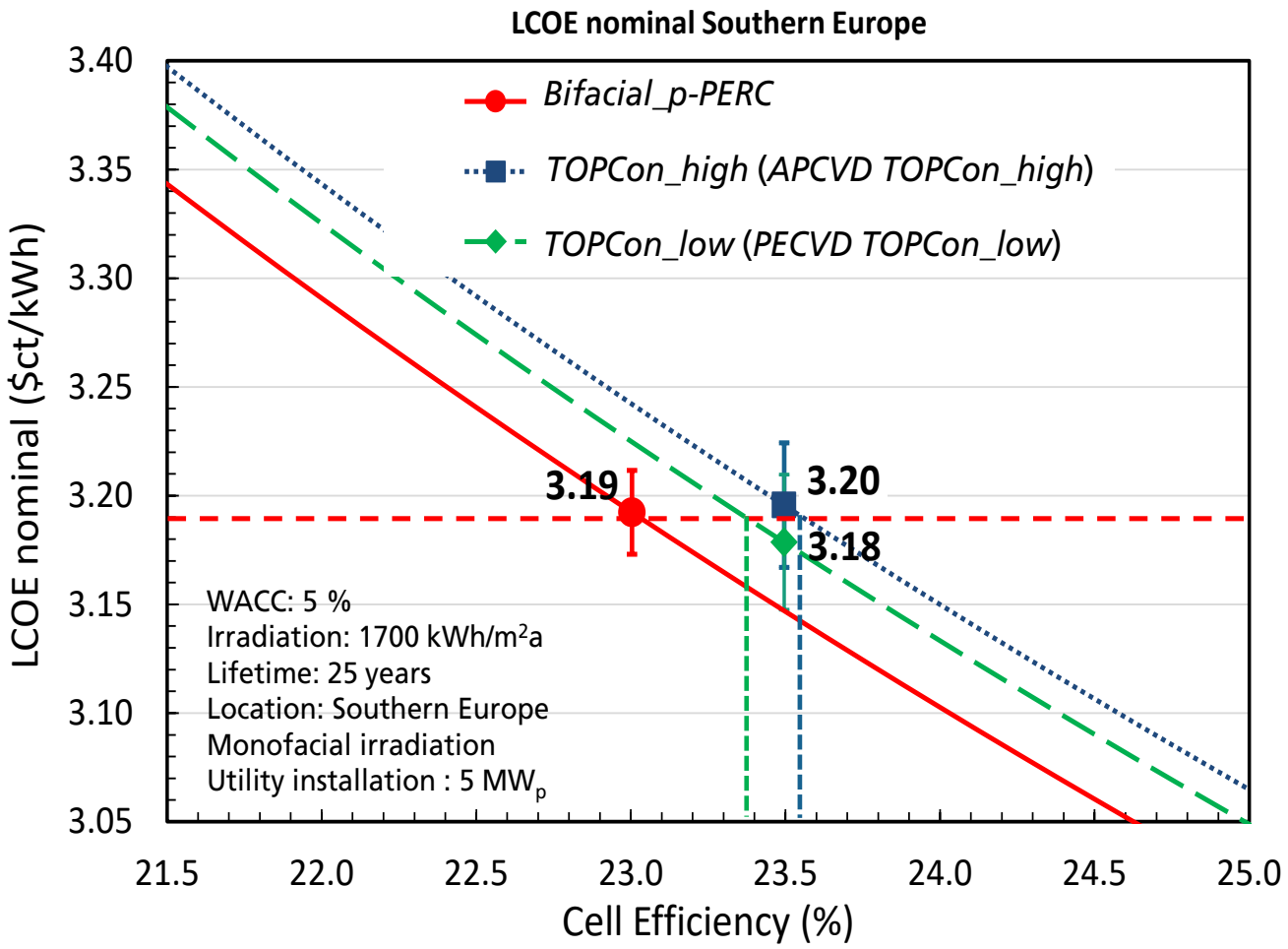
New plating result **24.0%**



Grübel *et al.*, "Progress of Plated Metallization for Industrial Bifacial TOPCon Silicon Solar Cells", Prog Photovolt (2021);

Cost of ownership - PERC vs TOPCon
Levelized Costs of Electricity (LCOE)

- Efficiency matters!



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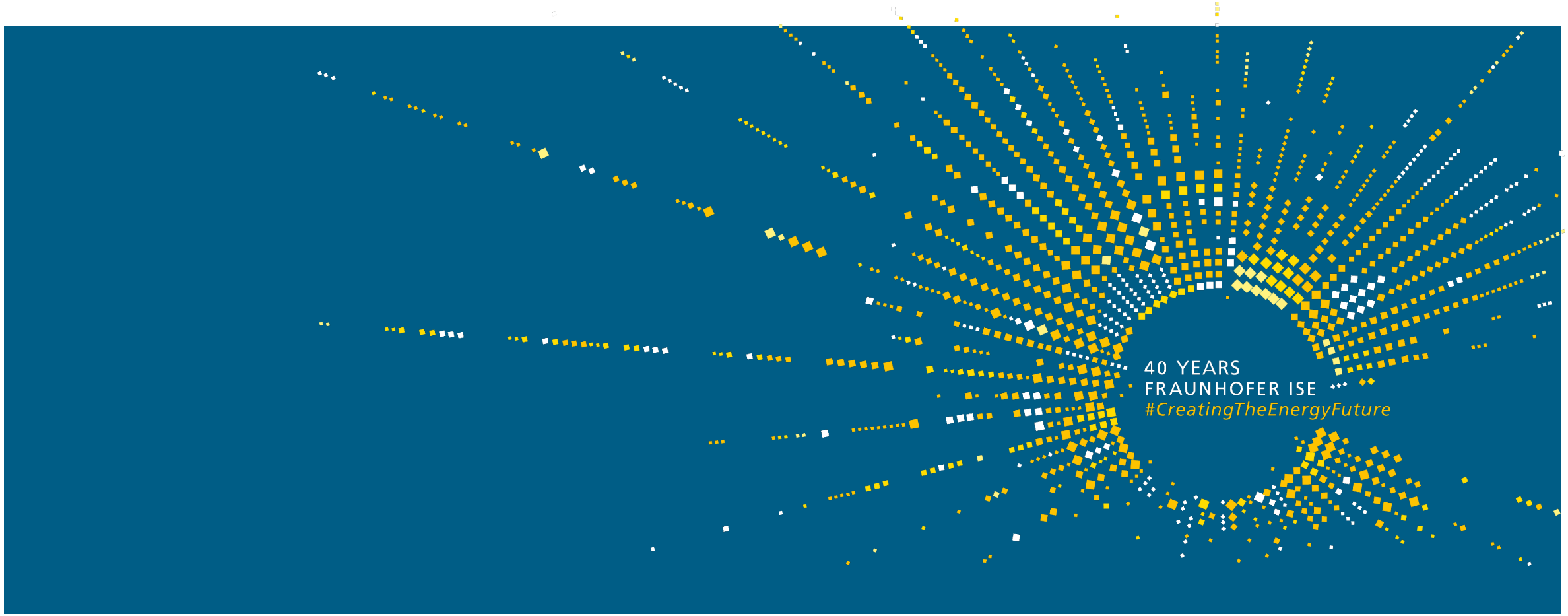

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