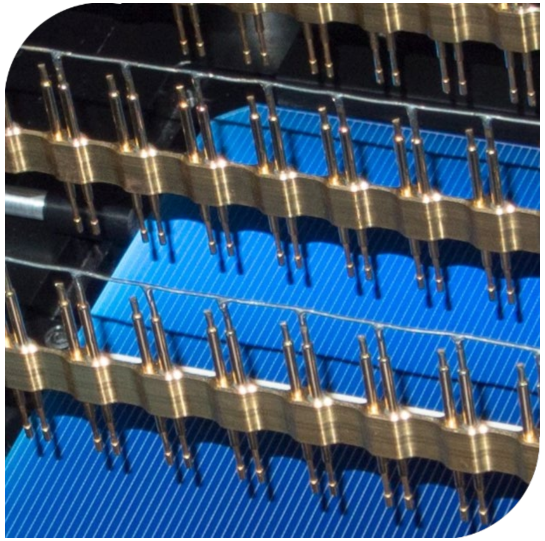



Status and Further Developments of polyZEBRA Cell Technology

Valentin D. Mihailetchi, Jonathan Linke, Florian Buchholz, Joris Libal, Christoph Peter, Jan Hoß, Vaibhav Kuruganti, Saman Sharbaf Kalaghichi, Jan Lossen, Lejo Joseph

ISC research for a sunny future

Outline

- Motivation
- polyZEBRA – a low cost TBC technology
  - Process flow
  - Efficiency status
  - Further performace improvements
  - Cost consideration
  - Alternative process route
- Summary

Back Contact Market Share

- SunPower (Maxeon Technology): Cu plating, Module Eta ≤ 23.0%
- AIKO (ABC technology): Cu plating/Screen printing, Module Eta ≤ 24,8%
- Longi (Hi-MO X6): p-type TBC, Module Eta ≤ 23.3%
- LG (NeON R technology): no longer in production!

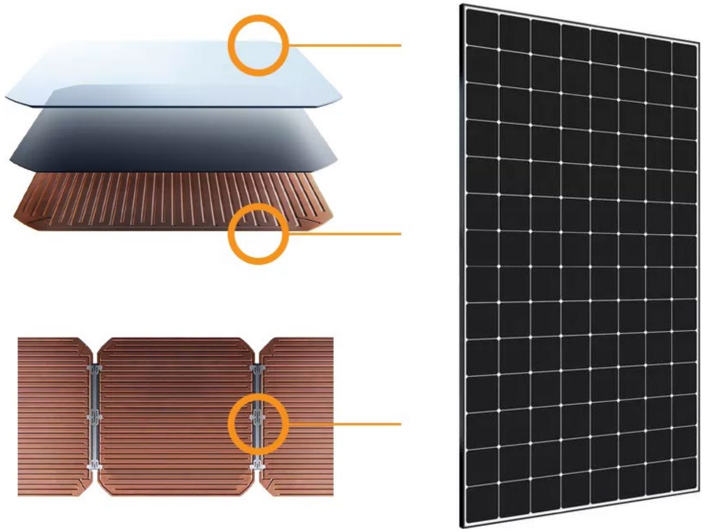
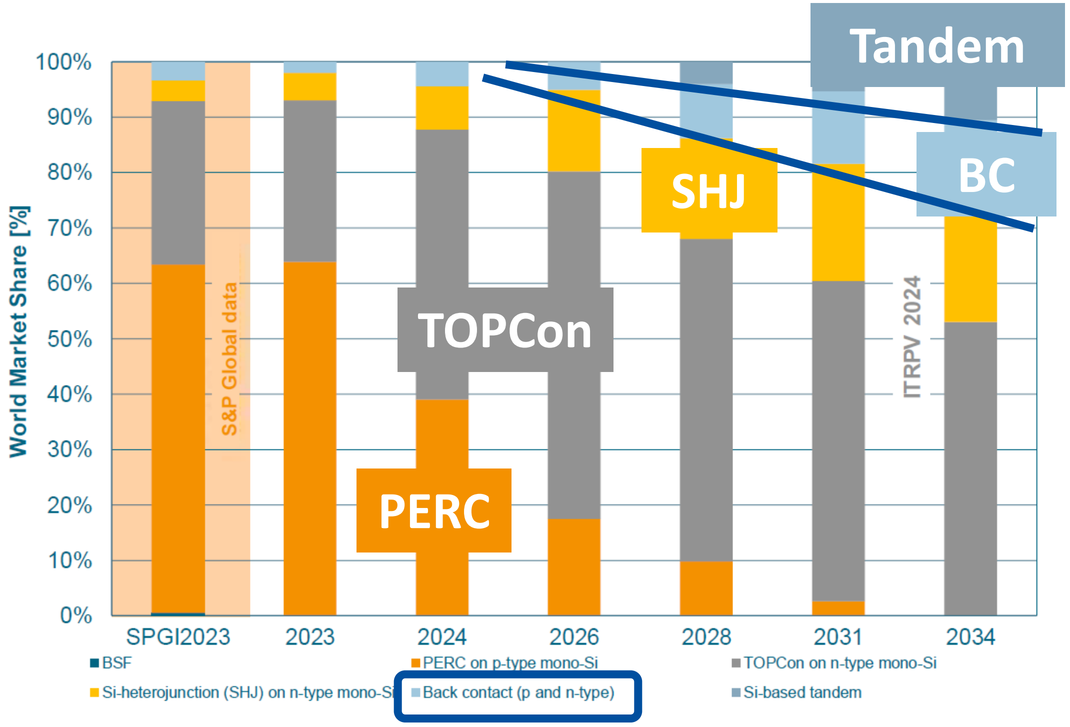


Image credit: SunPower

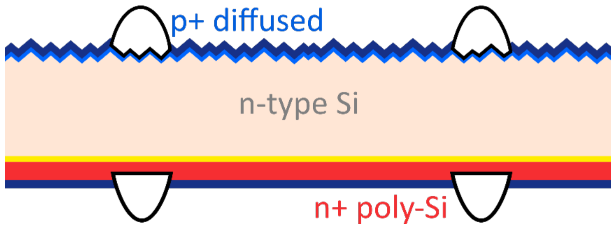
Image credit: AIKO



M. Fischer et al., "International Technology Roadmap for Photovoltaics (ITRPV) 2023 Results," 15th Edition (2024)

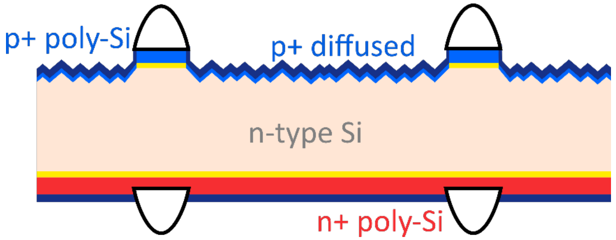
Our cell concepts with polysilicon

TOPCon (24.2%)

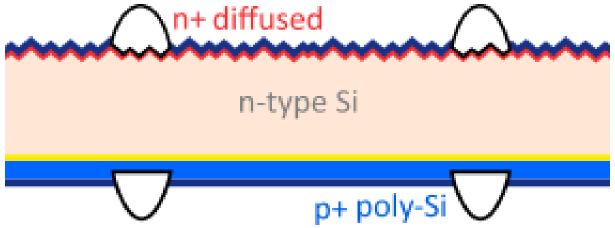


n+ poly-Si contact

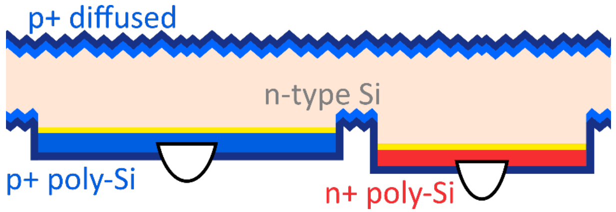
Integrating p+ poly-Si



TOPCon-SelFi[1]

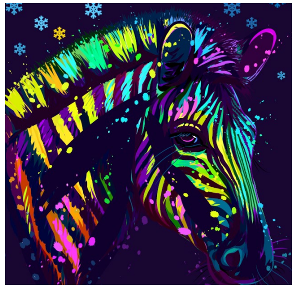


TOPCon-RJ (HOBIT)[2]



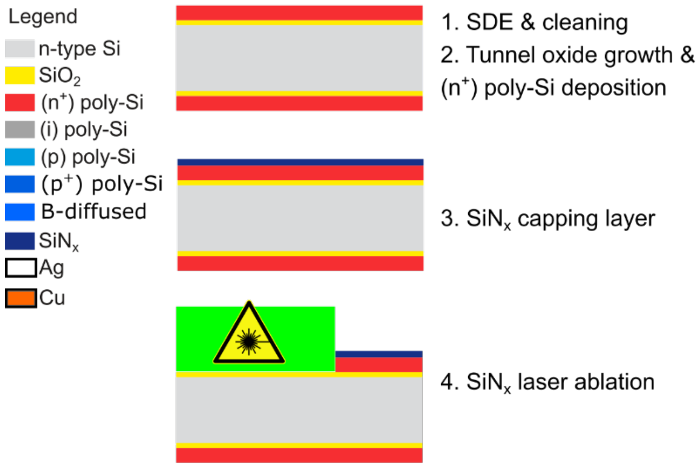
TOPCon-IBC

polyZEBRA[3]

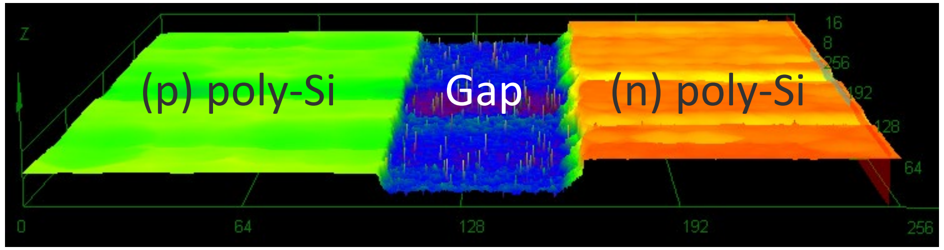


[1] J. Hoss et al., EPJ Photovolt., to be published (2024)
[2] V. V. Kuruganti et al., EUPVSEC (2023)
[3] J. Linke et al., EUPVSEC (2024)

polyZEBRA process Flow



J. Linke et al., EUPVSEC (2024)

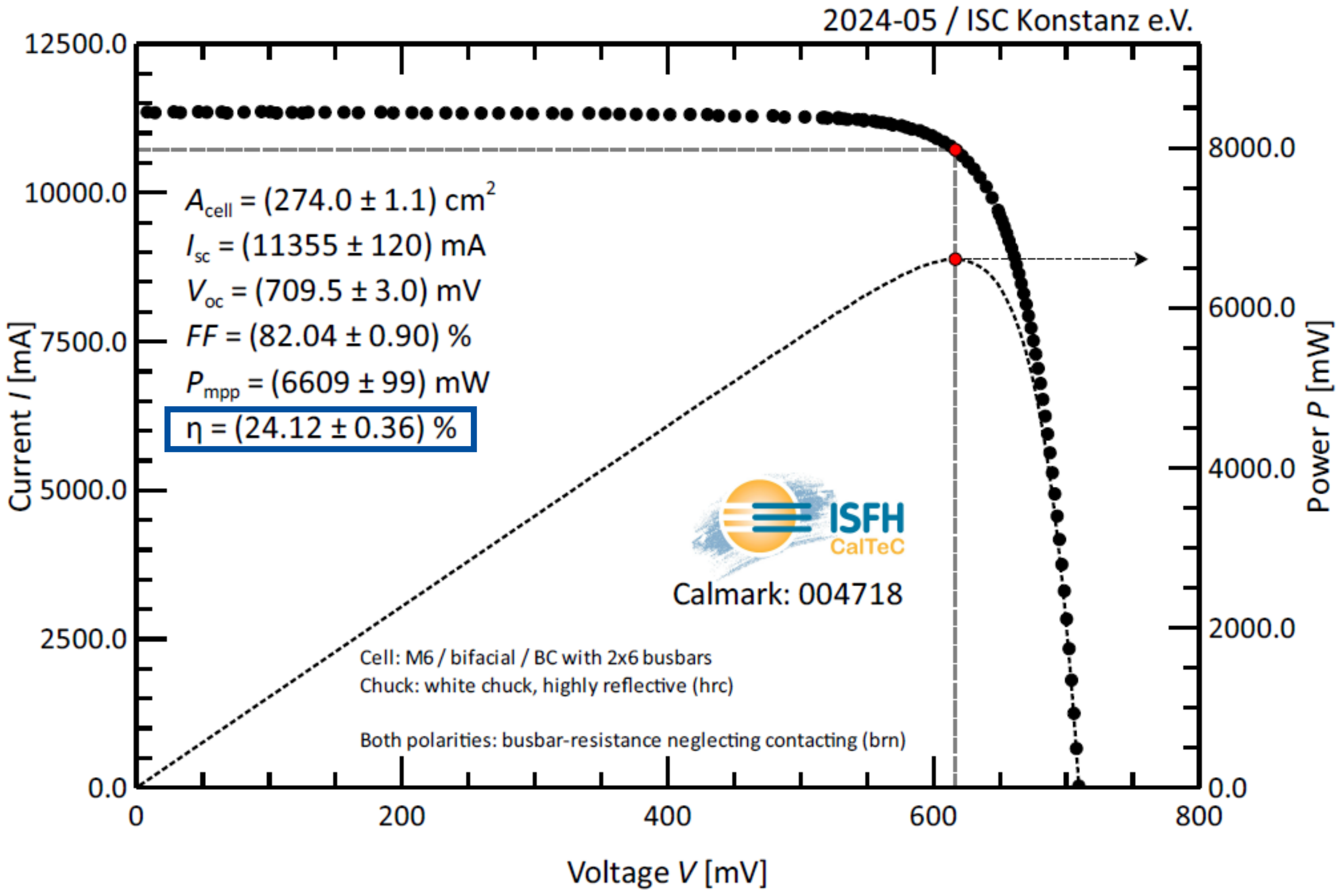


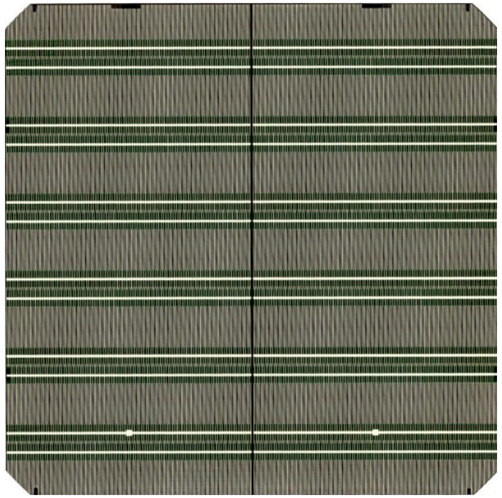
Key features:

- Laser-induced mask ablation (4.)
- Laser-induced dopant activation (8.)
- No single-side etching required → Compatible with all poly-Si deposition techniques (5./9.)
- Screen-print metallization Ag/Cu[3] (12.)

[3] N. Chen et al., Solar RRL 7 (2022)

Certified Efficiency 24.12%

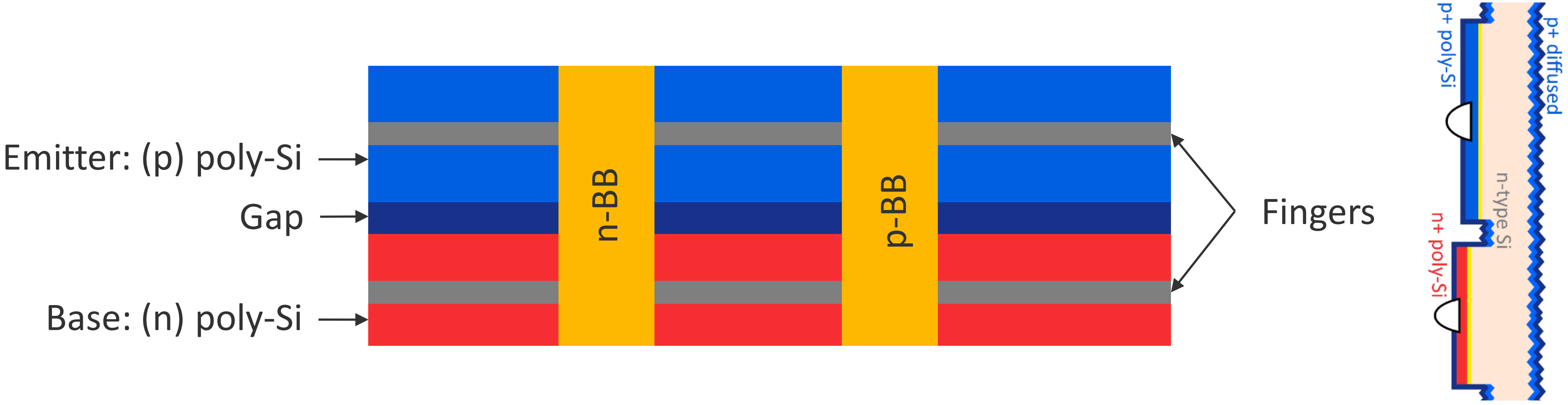




Loss analysis and further efficiency improvements

- Quokka3 three-dimensional modelling of polyZEBRA cell
  - with input optical, electrical, and geometrical data from experimental cell

- Unit cell design:



J. Linke et al., EUPVSEC (2024)

Simulation of current best cell

- Experiment-based input parameters
- Exceptions:
  - τ_{bulk}: Match simulated V_{oc} to measured cell precursor iV_{oc}
  - $J_{0,met,(n)\ poly\text{-}Si}$ = 50 fA/cm²
  - $J_{0,met,(p)\ poly\text{-}Si}$: Match simulated V_{oc} to measured cell V_{oc}
- Baseline simulation results:

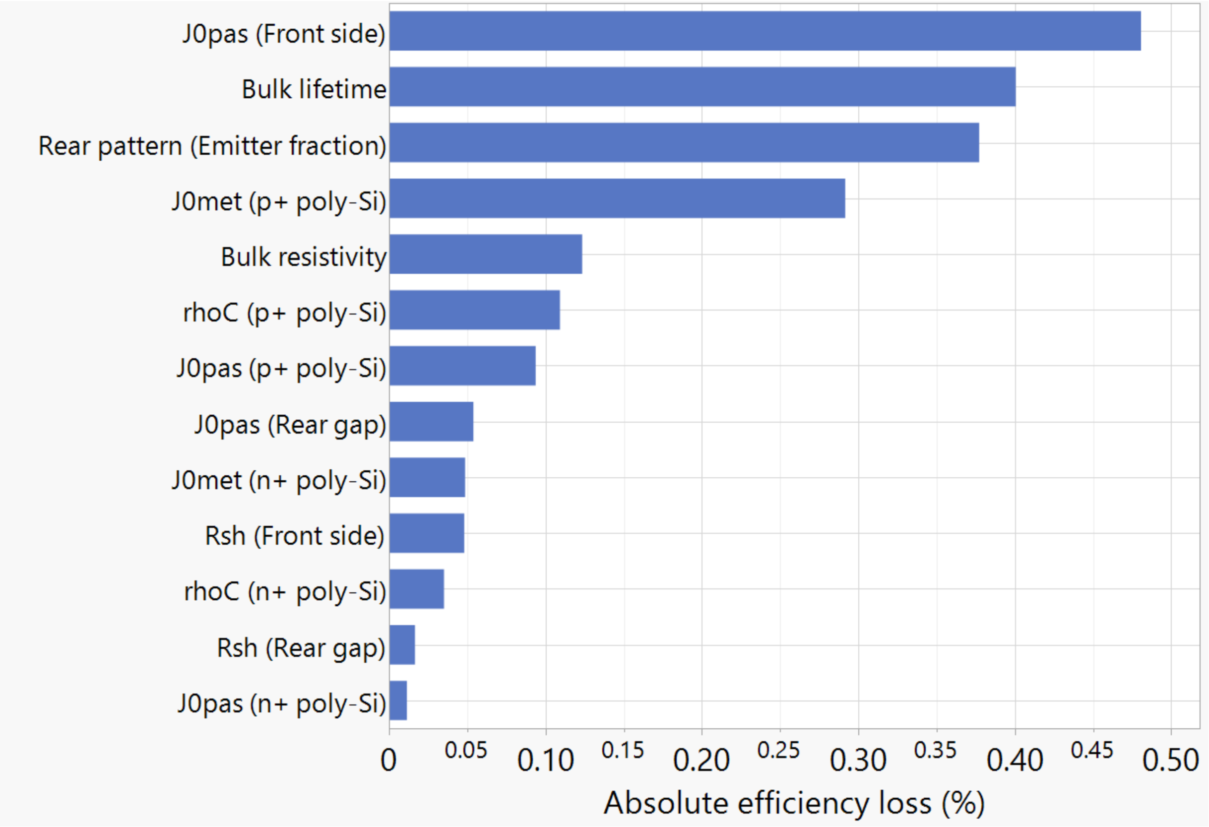
	η (%)	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)
Certified cell	24.12 ± 0.36	709.5 ± 3.0	41.4 ± 0.4	82.04 ± 0.90
Simulation baseline	24.14	709.0	41.33	82.38

J. Linke et al., EUPVSEC (2024)

Baseline input parameters	
Wafer size	M6
#BB	6BB
τ_{bulk}	3 ms
Cell pitch	800 µm
W_{base}	290 µm
W_{emi}	360 µm
W_{gap}	75 µm
$J_{0,pass,(n)\ poly\text{-}Si}$	1 fA/cm²
$J_{0,pass,(p)\ poly\text{-}Si}$	10 fA/cm²
$J_{0,pass,gap/front}$	13 fA/cm²
$J_{0,met,(n)\ poly\text{-}Si}$	50 fA/cm²
$J_{0,met,(p)\ poly\text{-}Si}$	500 fA/cm²
$R_{sheet,(n)\ poly\text{-}Si}$	55 Ωcm
$R_{sheet,(p)\ poly\text{-}Si}$	175 Ωcm
$R_{sheet,gap/front}$	490 Ωcm
$\rho_{c,(n)\ poly\text{-}Si}$	0.9 mΩcm²
$\rho_{c,(p)\ poly\text{-}Si}$	2.8 mΩcm²

Simulation of current best cell

- Power Loss Analysis (PLA)

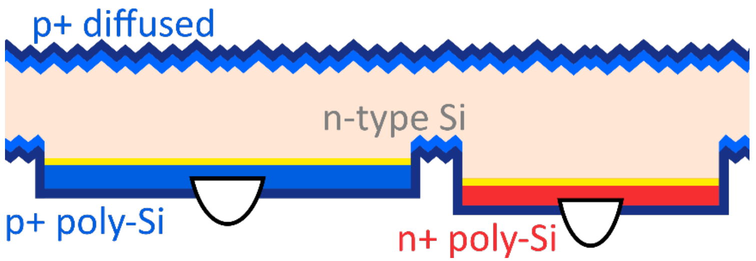


Main optimization topics:

- Front side passivation → p+ diffusion profile, passivation stack
- Bulk lifetime → better cleaning, gettering?
- Rear pattern → increase emitter fraction
- p+ poly passivation and metallization → reduce J0pas, J0met, rhoC

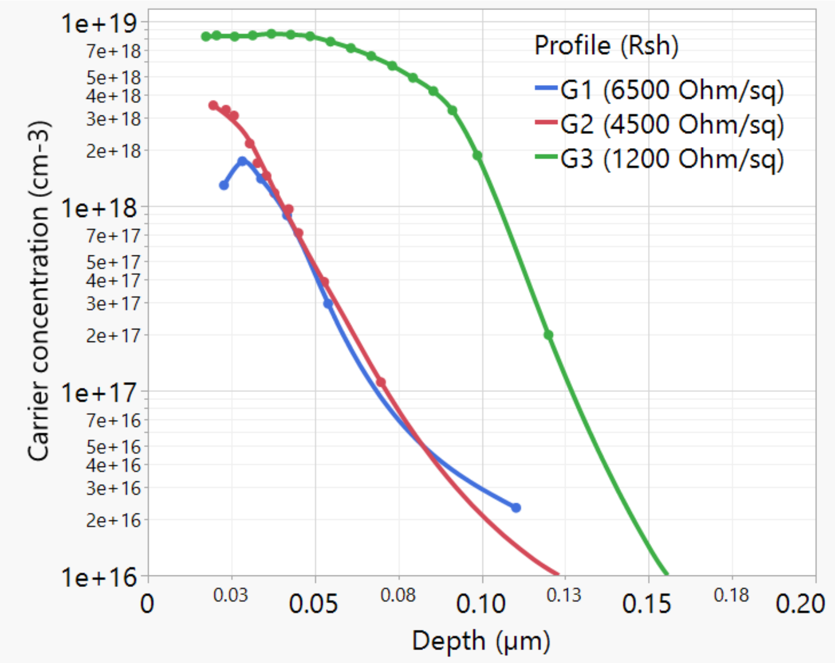
Optimization of front side & gap passivation

- Front side & gap ≈ 60% of total solar cell surface
  → Excellent surface passivation required



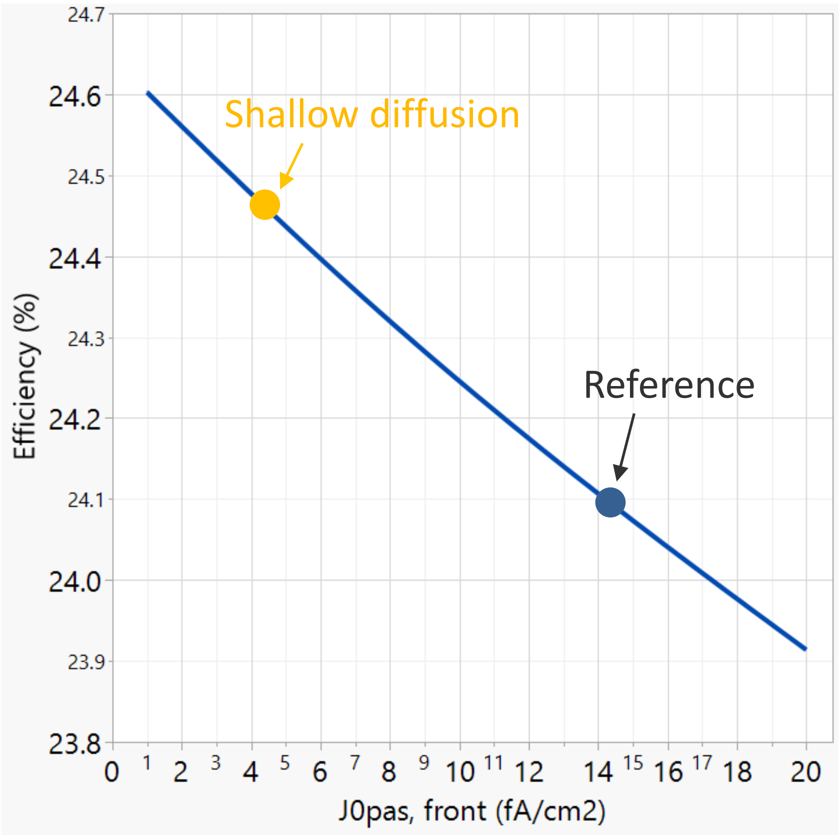
Solution:

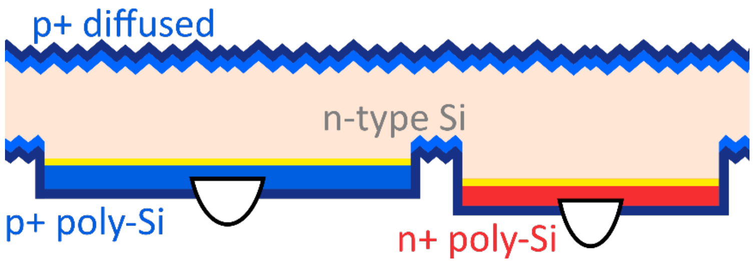
- Shallow boron diffusion with low surface concentration
- Improved PECVD-AlOx, pALD-Al2O3 passivation



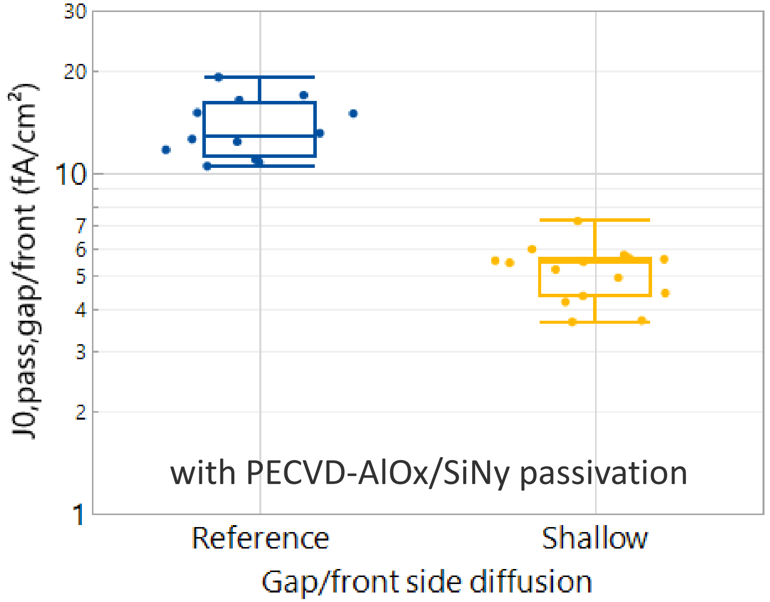
Optimization of front side & gap passivation

- Modelling prediction:





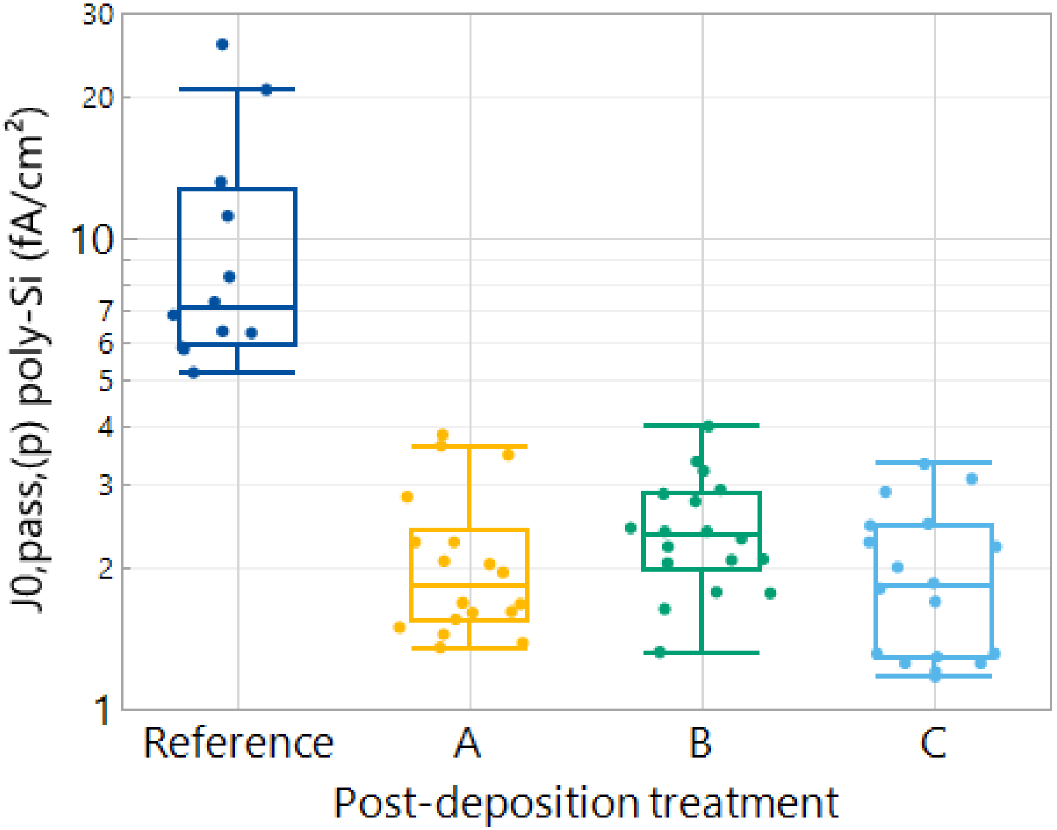
Results on lifetime test structures



Optimization of p+ poly-Si passivation

- Post-deposition treatment of tunnel oxide reduces surface recombination

- Average on local test structures:
  $J_{0,pass,(p)\ poly\text{-}Si} = (1.9 \pm 0.4)\ fA/cm^2$

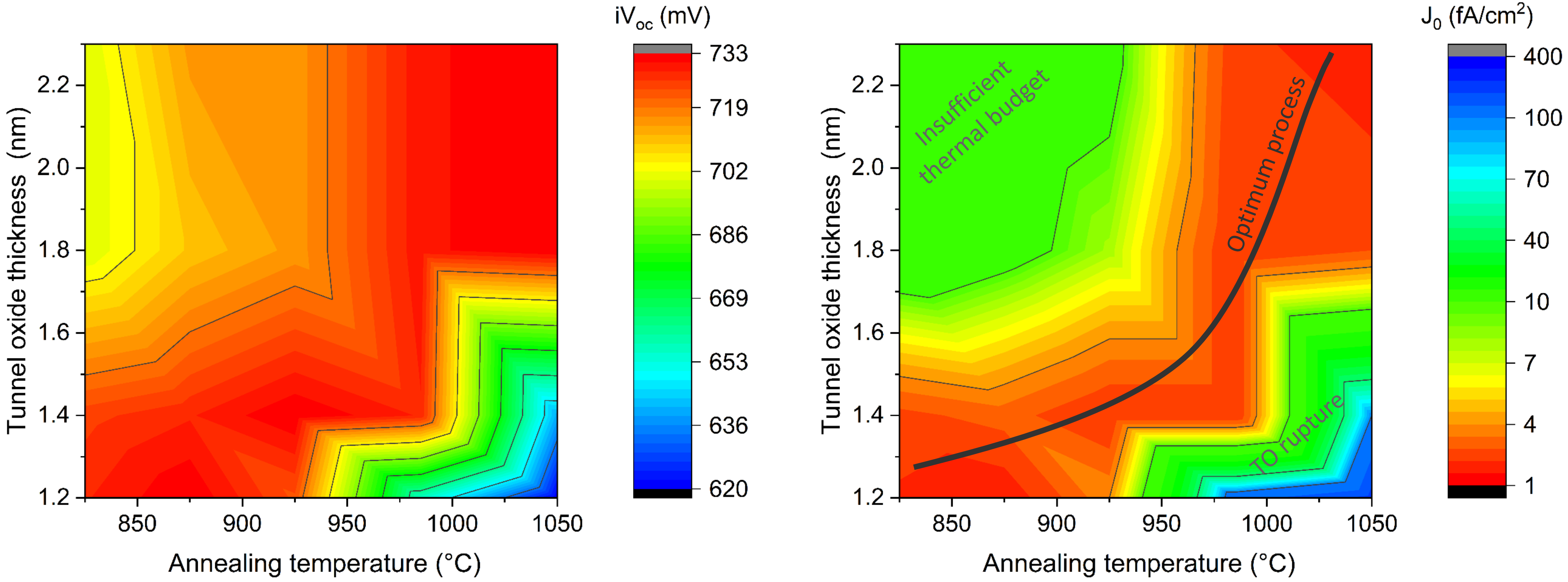


J. Linke et al., EUPVSEC (2024)

Optimization of p+ poly-Si passivation

Tunnel oxide thickness and p+ poly-Si annealing temperature optimization

Results on lifetime test structures



This work was funded by the German Federal Ministry for Economic Affairs and Energy within the research project "**HOBIT**" (No. 03EE1121B)

Optimization of p+ poly-Si metallization

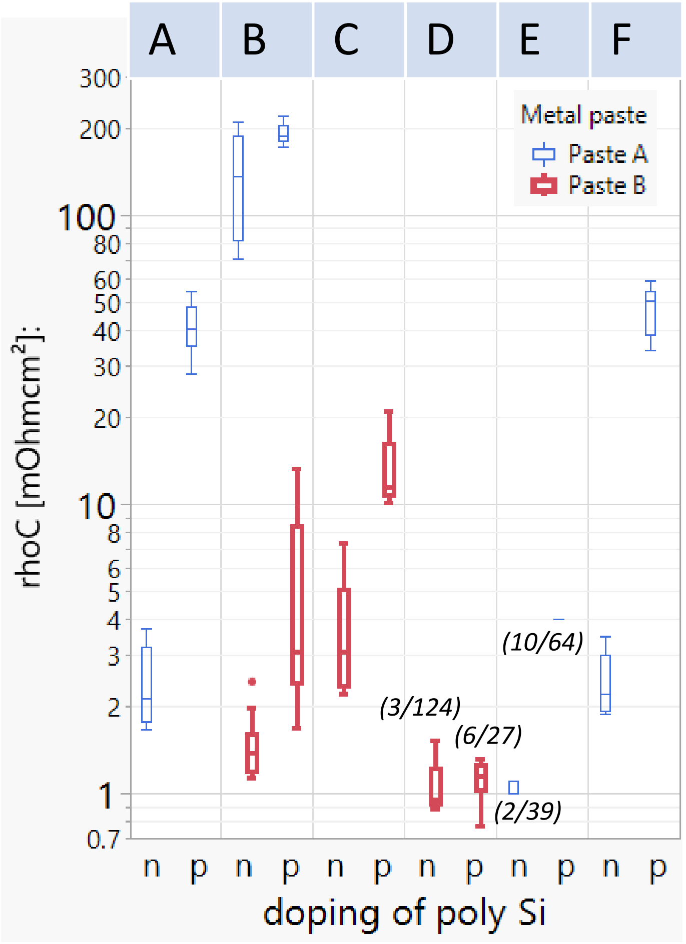
- Improved Ag screen printing and firing:
  - Co-optimization of J0pas, J0met and contact resistance (rhoC) for both p- and n-doped poly-Si

- Results obtained on test structures:

$J_{0,met,(p)\ poly\text{-}Si} \leq 100\ fA/cm^2$

$rhoC \leq 1.5\ m\Omega cm^2$

Firing recipe



Values in brackets: J0pas/J0met in fA/cm^2

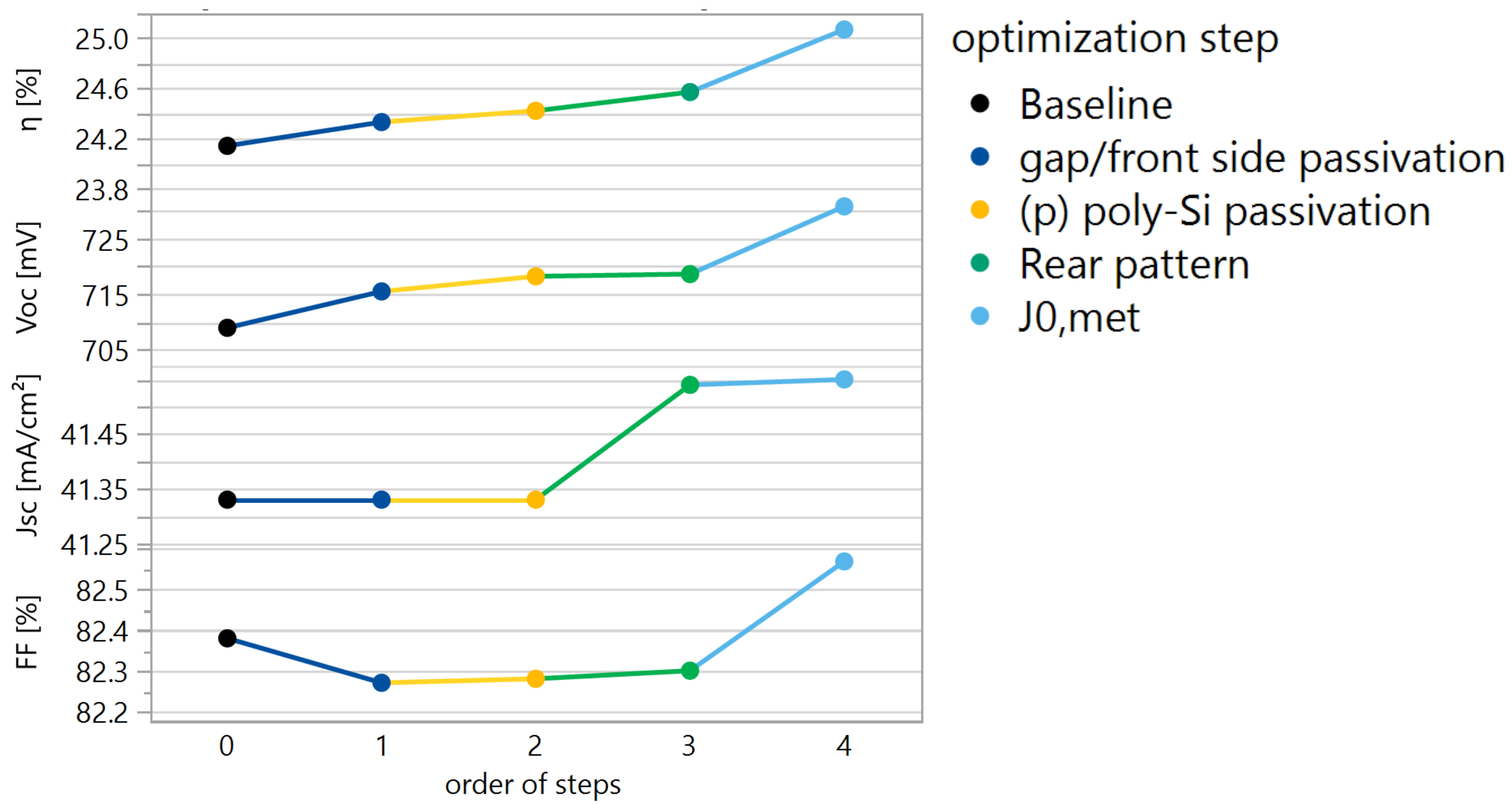
BURST

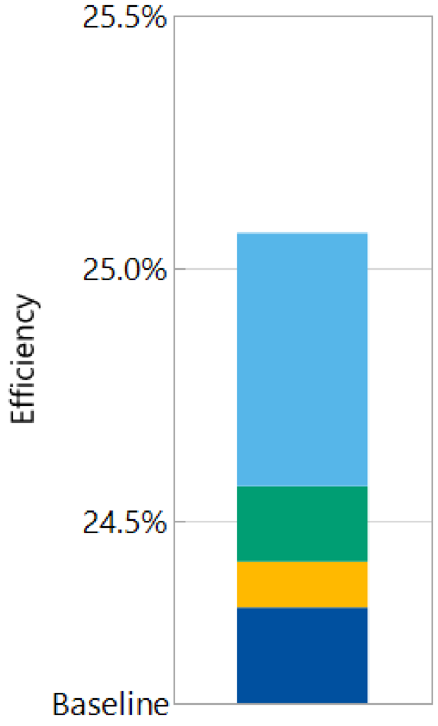
Funded by the European Union

The BURST project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101146684

Simulated Cell Efficiency Potential

- Based on experimental data on test structures

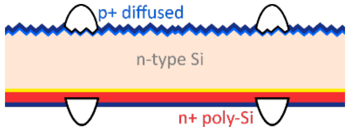




J. Linke et al., EUPVSEC (2024)

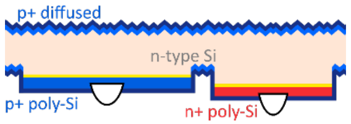
Cost considerations

TOPCon



- Alkaline batch
- BCl3 diffusion
- HF inline
- Alkaline batch
- PECVD-SiO2+a-Si(n)
- annealing
- HF inline
- Alkaline batch
- ALD AlOx (dl)
- PECVD SiNx
- PECVD SiNx
- LECO & Screen printing (4x)
- IV+sorting

polyZEBRA



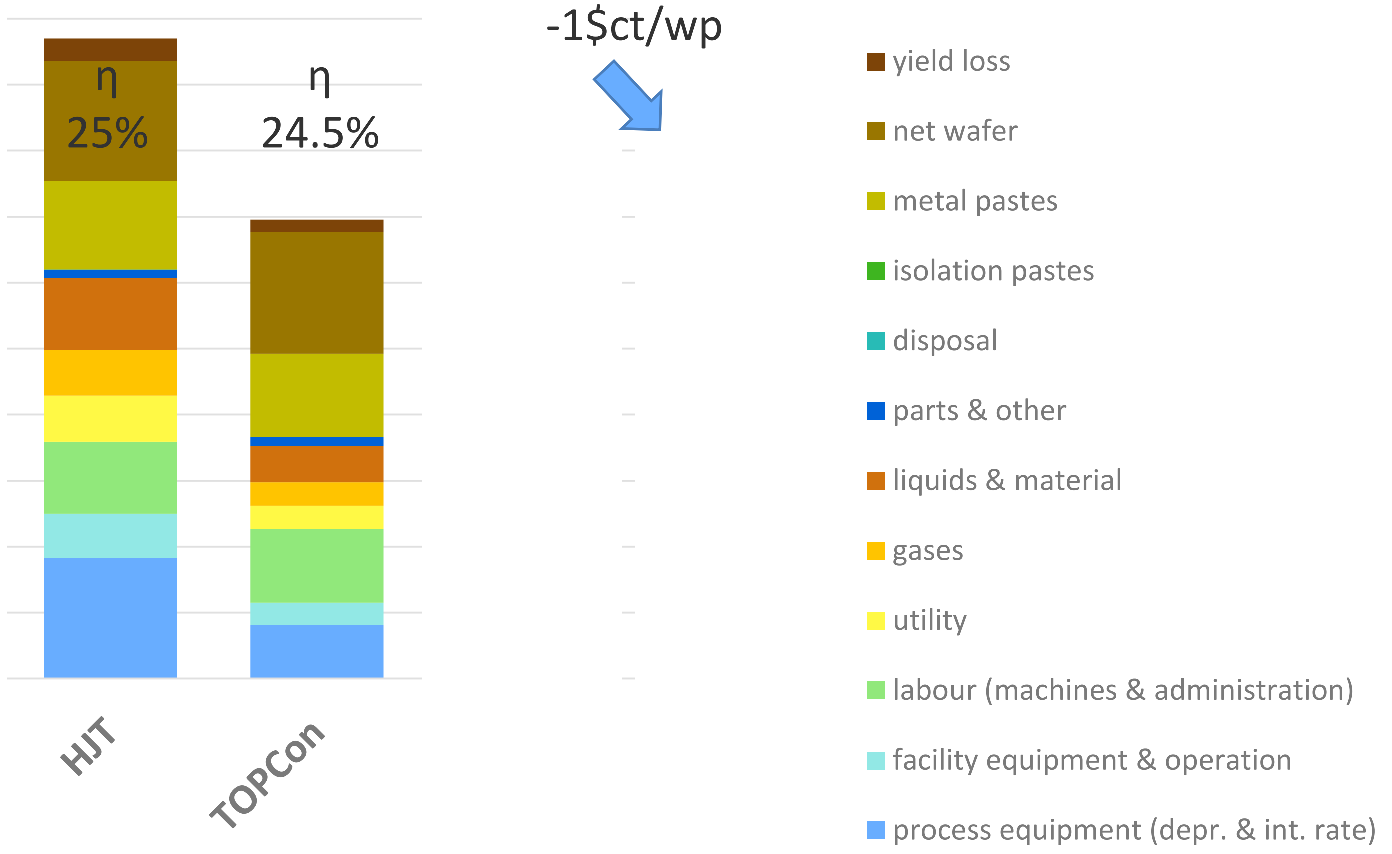
- Alkaline batch
- PECVD-SiO2+a-Si(n)
- Laser
- Alkaline batch
- PECVD-SiO2+a-Si(i)
- BCl3 diffusion
- HF batch
- Laser
- Alkaline batch
- BCl3 diffusion
- ALD AlOx (sl)
- PECVD SiNx
- PECVD SiNx
- LECO(?) Screen printing (5x)
- IV+sorting

Process equipment relative to TOPCon

+ 2x Laser (similiar to SE)
+ PECVD-SiO2+a-Si(i)
+ Extra small HF batch
- No inline tools required
= Short BCl3 instead of annealing
+ Single load AlOx
+ Extra screen printing step
= LECO under investigation

Cost considerations

Cost breakdown – cell process (cost/Wp)



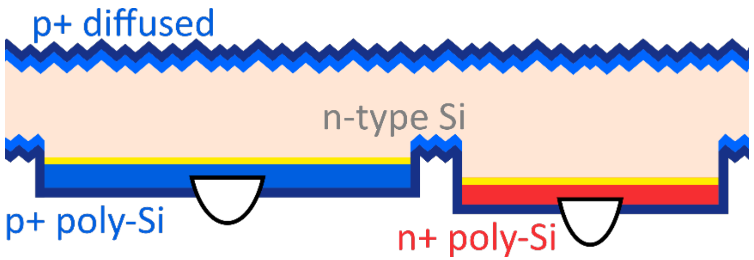
→ Higher CAPEX mainly due to need for extra lasers (pessimistic scenario)

→ Cu paste costs assumed @300$/Kg

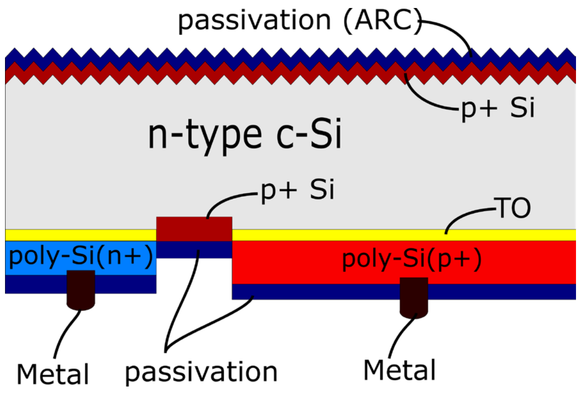
Copprint

Alternative process route

polyZEBRA (PECVD/LPCVD)



TOPCon IBC (PVD)



Key processes:

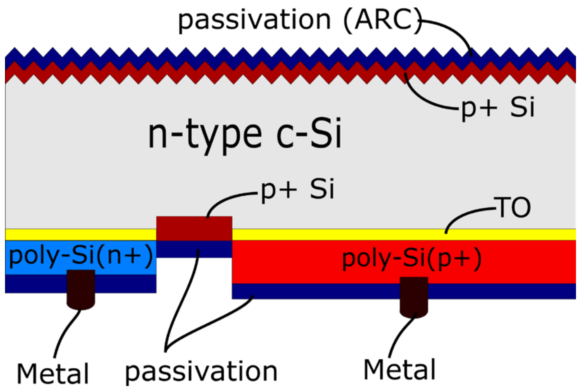
- PECVD or LPCVD a-Si deposition for doped poly-Si
- Laser ablation and laser dopant activation for poly-Si structuring

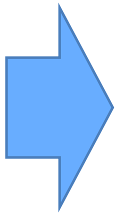
Key processes:

- PVD a-Si sputtering for doped poly-Si layers
- Laser ablation for poly-Si structuring

Alternative process route

TOPCon IBC (PVD)





Key processes:

- Only one tunnel oxide / a-Si deposition step
- PVD inline single side sputtering (by industry leader VA tool)
- laser ablation for poly-Si patterning
- Co-annealing for n+ and p+ poly-Si

Under development within the framework of BMWK project "**PariS**" (FKZ: 020E-100636800)

Bundesministerium für Wirtschaft und Klimaschutz

Summary

- Certified champion cell efficiency: **24.12%**
- Cell efficiency potential from experiment-based simulations: **>25%**
- Next steps: Transfer results from test structures to the cell
- **Production cost of Cu-polyZEBRA** module at scale close to **TOPCon**
- Alternative fabrication route of TBC cells using **PVD inline sputtering** of a-Si layers under development

research
for a sunny future

Thank you for your attention

V.D. Mihailetchi et al., Back Contact Workshop, Delft, 2024

IBC4EU

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