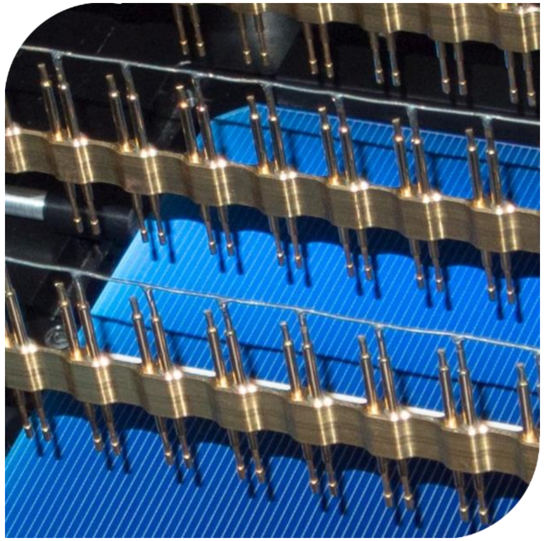


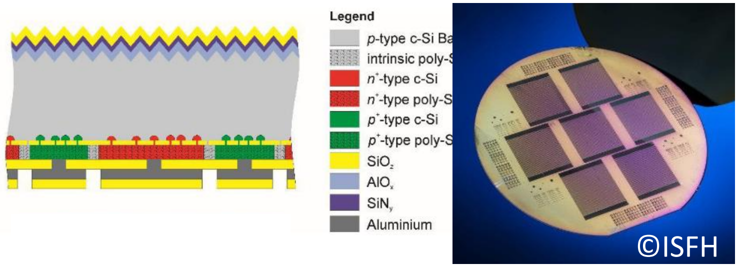

polyZEBRA – A both polarity passivating contact IBC cell

J. Linke, F. Buchholz, C. Peter, J. Hoß, J. Lossen

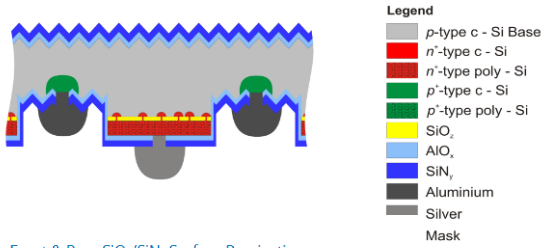
ISC research for a sunny future

Overview poly-Si based IBC concepts

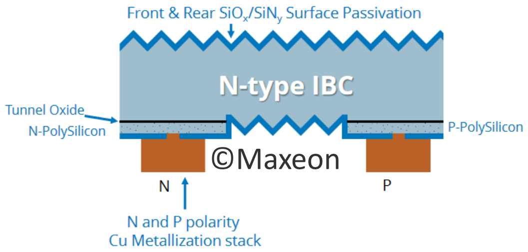
- ISFH: p-IBC record cell both polarities poly-Si[1]
  - Industrially irrelevant



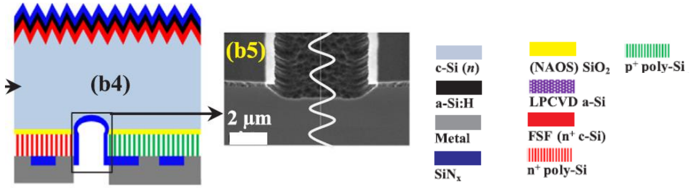
- ISFH: POLO-IBC current development with n⁺ poly-Si and p Al-BSF[2]
  - (see talk Verena Mertens this workshop)



- SunPower (Maxeon), LG: Both polarities poly-Si/SiO_x
  - Industrially established, details unknown



- TU Delft: Cell area 2cm² in 2018[3], no following publication found



[1] Haase, F. et al., *Sol. Energy Mater. Sol. Cells* 186 (2018): 184-193.
[2] Patented by Bende, E., Wu, Y., Anker, J., EP3685445A1.
[3] Yang, G. et al., *Sol. Energy Mater. Sol. Cells* 186 (2018): 9-13.

From ZEBRA to polyZEBRA

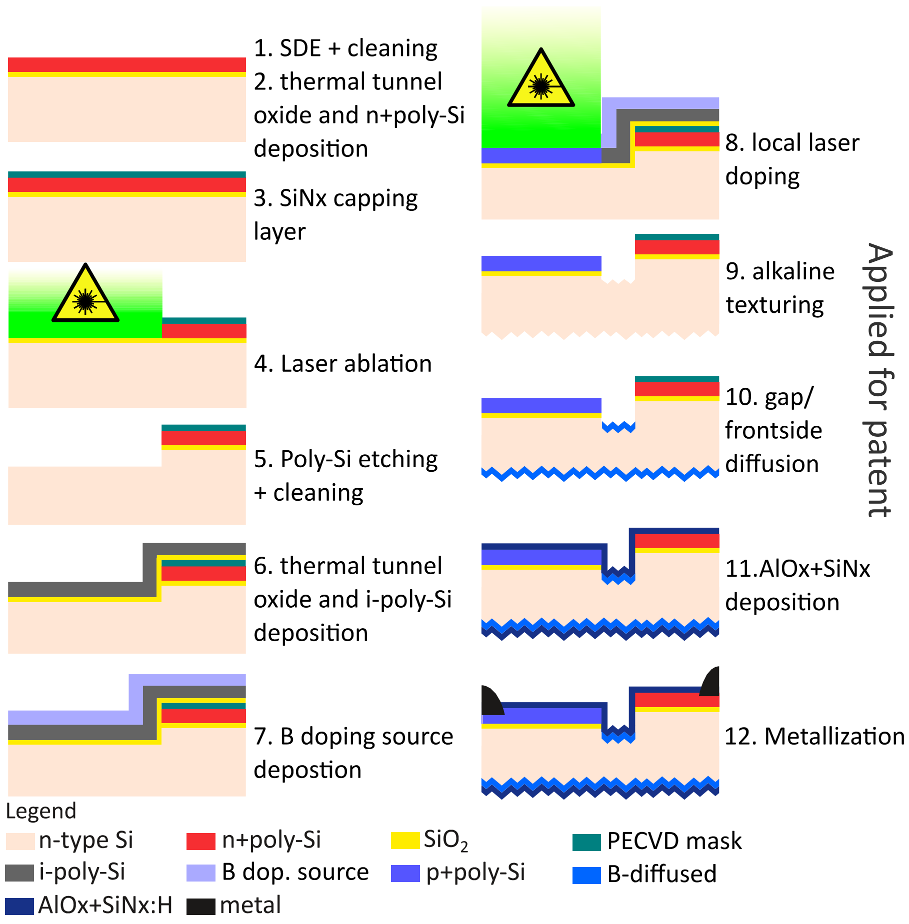
<u>ZEBRA</u>

- p/n regions diffused
- Direct contact of p/n regions
- >24% in production (see talk Jan Lossen this workshop)

<u>polyZEBRA</u>

- p/n regions poly-Si/SiO_x contacts
- Textured gap between p/n regions
- p^+ diffused gap and frontside

polyZEBRA process flow



Key processes:

- n^+ poly-Si patterning by local laser mask ablation (**4.**)
- p^+ poly-Si patterning by local laser activation of inactive dopants (**8.**)
  → High etch selectivity in alkaline solution[4] (**9.**)
- p-diffused gap ensures soft breakdown[5] (**10.**)
- Simultaneous printing of both polarities[6] (**12.**)

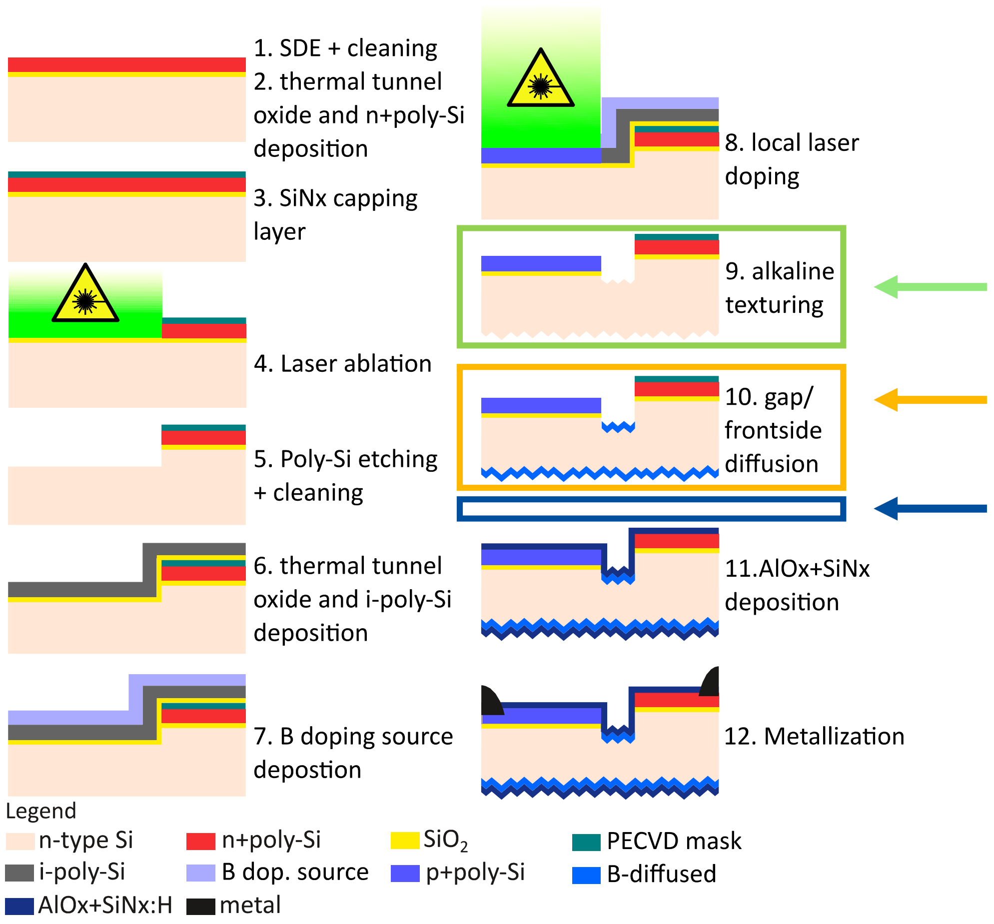
Compatible with industrially established ZEBRA process:

- Only few additional steps
- Standard ZEBRA metallization scheme
- 23.4% efficiency demonstrated with industrially relevant tools on full-area M6 wafer format

→ Upgrade from ZEBRA production line to polyZEBRA possible

[4] Buchholz, F. et al., *Proc. 38th EUPVSEC* (2021): 140-143. [5] Linke, J. et al., *Silicon PV* (2022): to be published. [6] Buchholz, F., Linke, J. et al., *Proc. WCPEC-8 (2022):* to be published.

polyZEBRA process flow

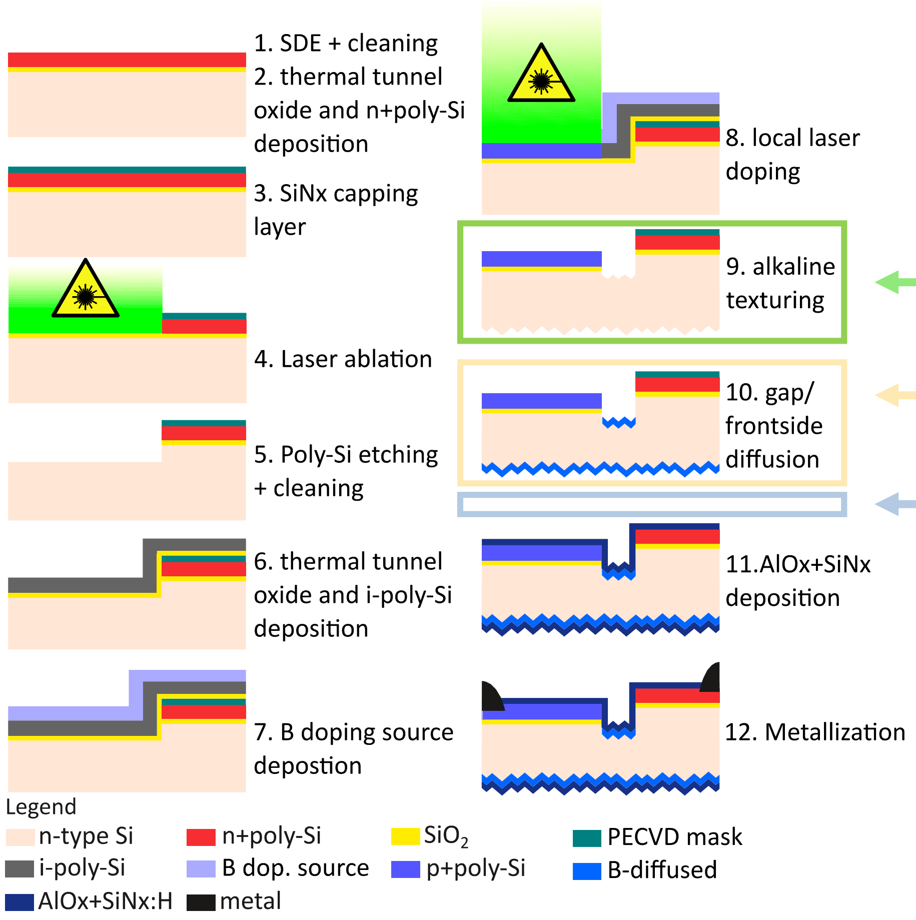


9: Etch resistance of laser-treated p^+ poly-Si in alkaline solution

10: Optimization of gap/frontside diffusion

Between 10/11: Remove or retain SiN_x mask protecting n^+ poly-Si?

polyZEBRA process flow



9: Etch resistance of laser-treated p^+ poly-Si in alkaline solution

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Etch resistance of laser-treated p$^+$ poly-Si in alkaline solution

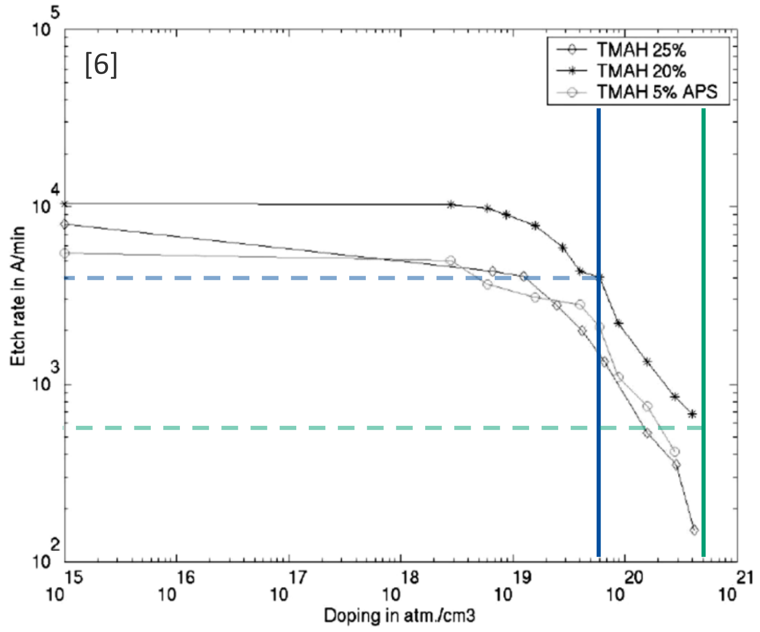
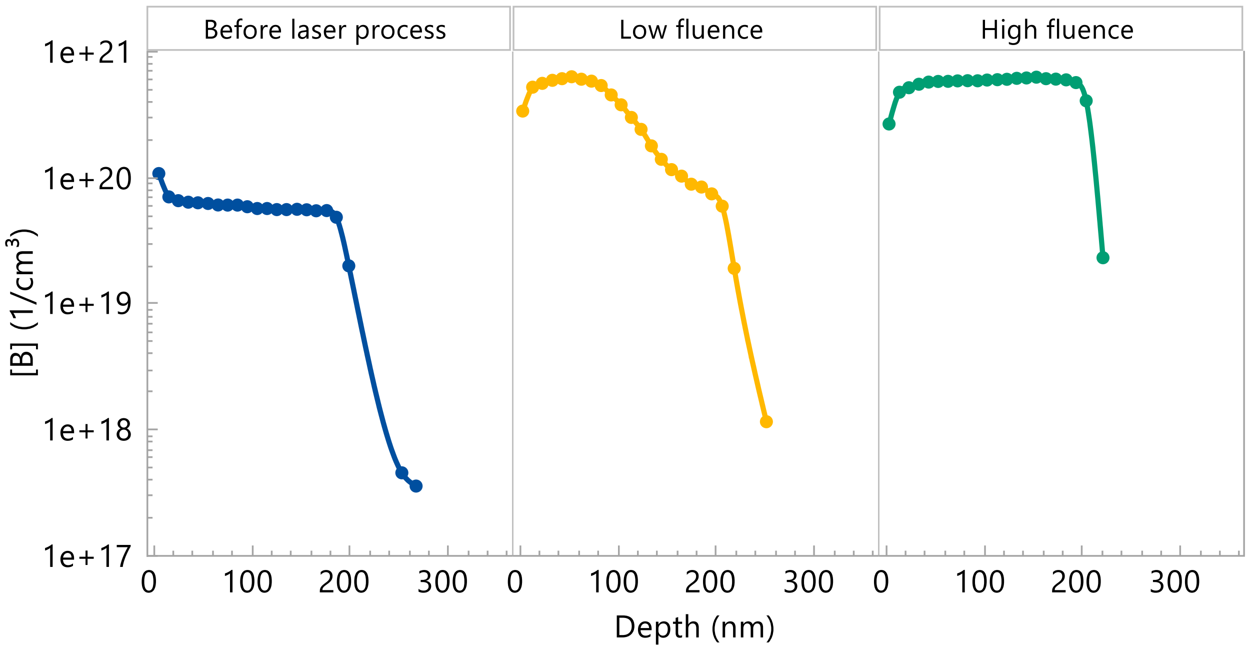


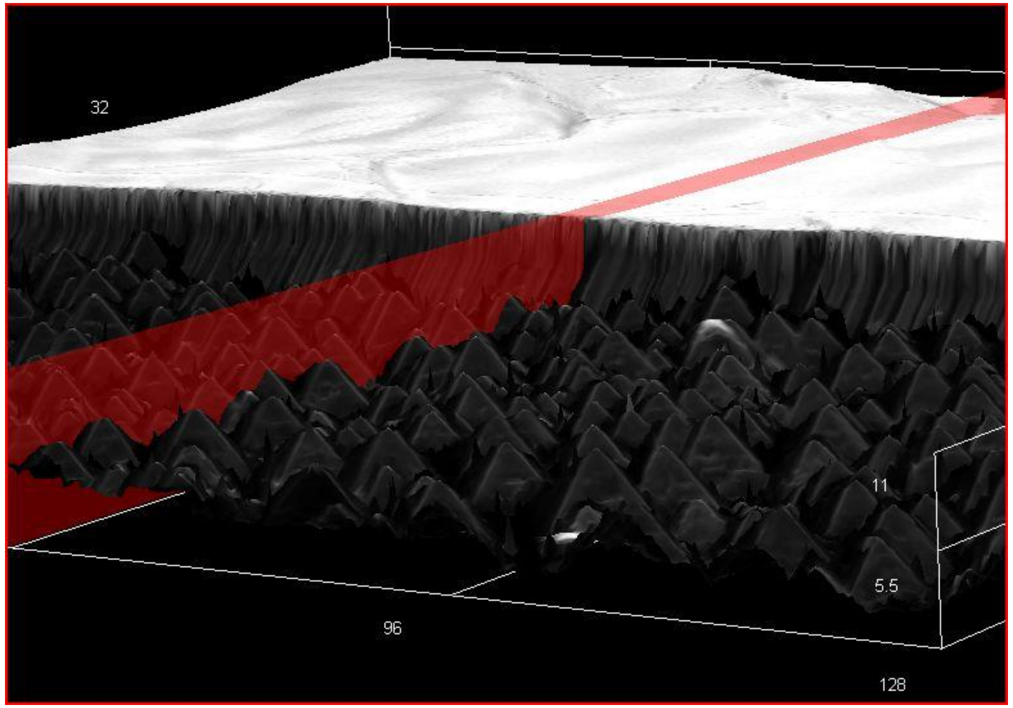
Figure 8: Polysilicon etch rate in different solutions.

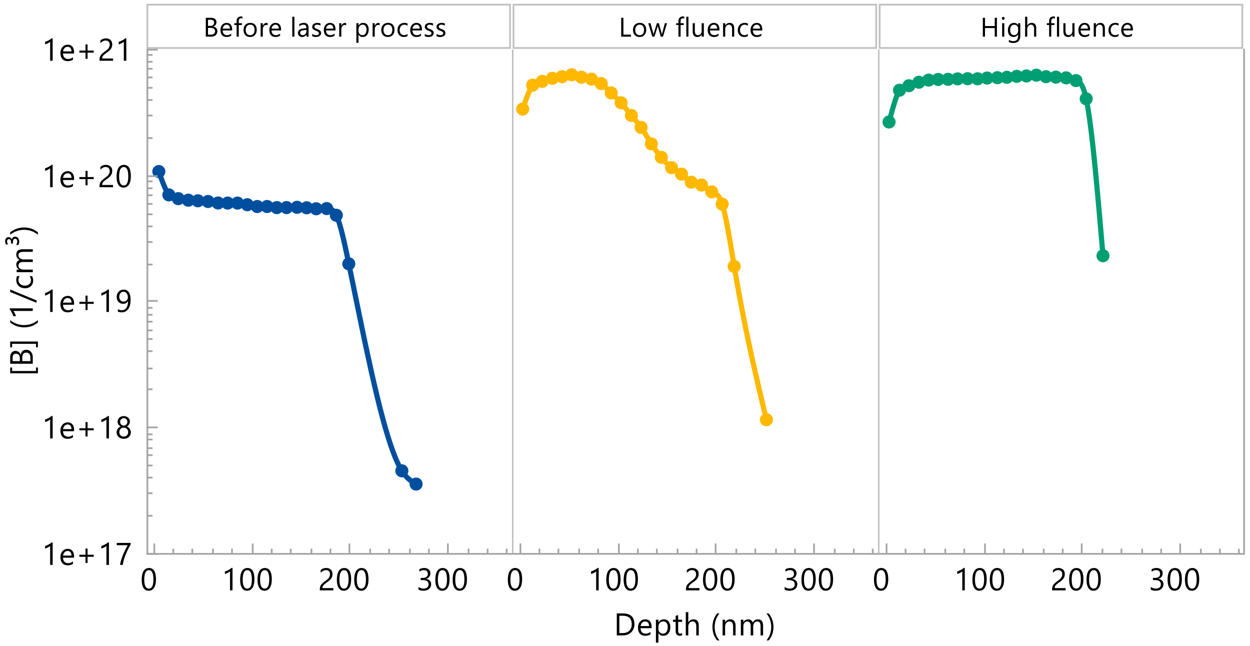


- Homogeneous B activation possible
- Gain factor ~10 in active [B] → Factor ~7 lower etch rate (according to [7])
- Measured etch selectivity 250-500

[7] Charavel, R. et al., *Proc. SPIE* 5116 (2003): 699-709.

Etch resistance of laser-treated p$^+$ poly-Si in alkaline solution





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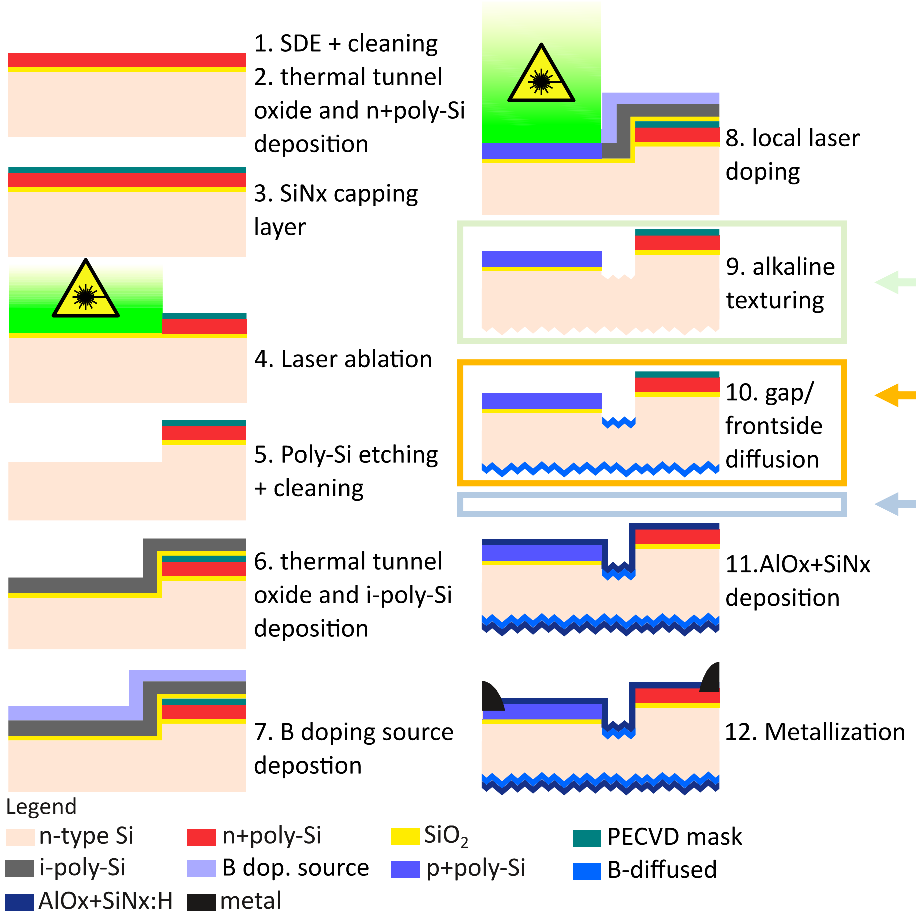
polyZEBRA process flow



9: Etch resistance of laser-treated p^+ poly-Si in alkaline solution

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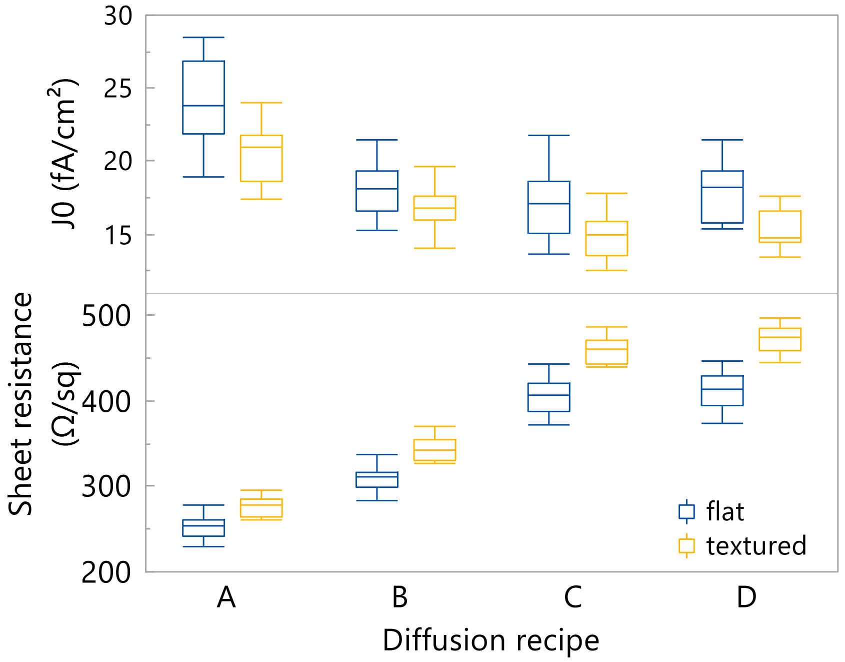
Between 10/11: Remove or retain SiN_x mask protecting n^+ poly-Si?

Optimization of gap/frontside diffusion

Recipe	Depo	Drive-in
Baseline	**840-900°C, 16 min**	**985°C, 20min**
A	830°C, 16 min	960°C, 5 min
B	820°C, 16 min	950°C, 20 min
C	**820°C, 16 min**	**925°C, 20 min**
D	810°C, 16 min	925°C, 20 min

Baseline: 32 fA/cm², 200 Ω/sq

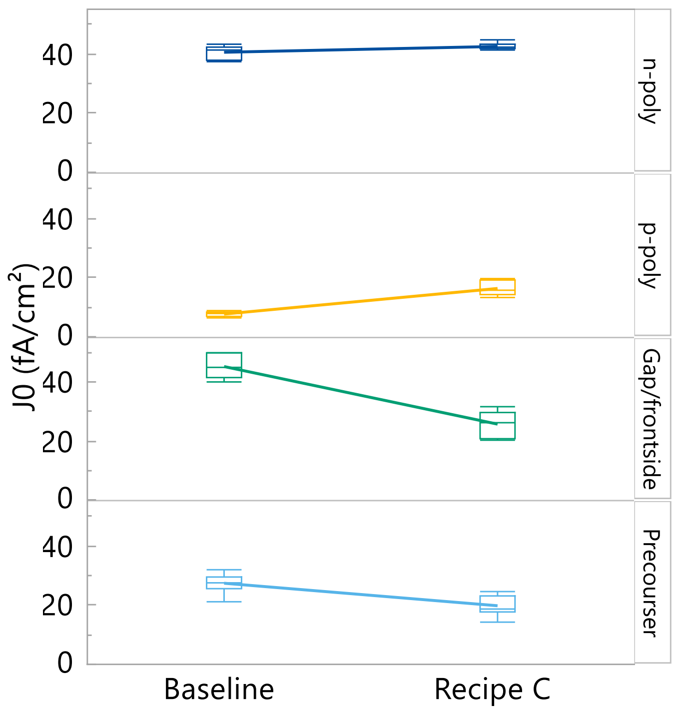


- Optimization towards J_0, R_{sheet} plays minor role
- Recipe C chosen for cell fabrication:
  Lowest J_0 on textured surface, slightly lower R_{sheet} than recipe D

[6] Buchholz, F., Linke, J. et al., *Proc. WCPEC-8 (2022):* to be published

Optimization of gap/frontside diffusion

Test structures:

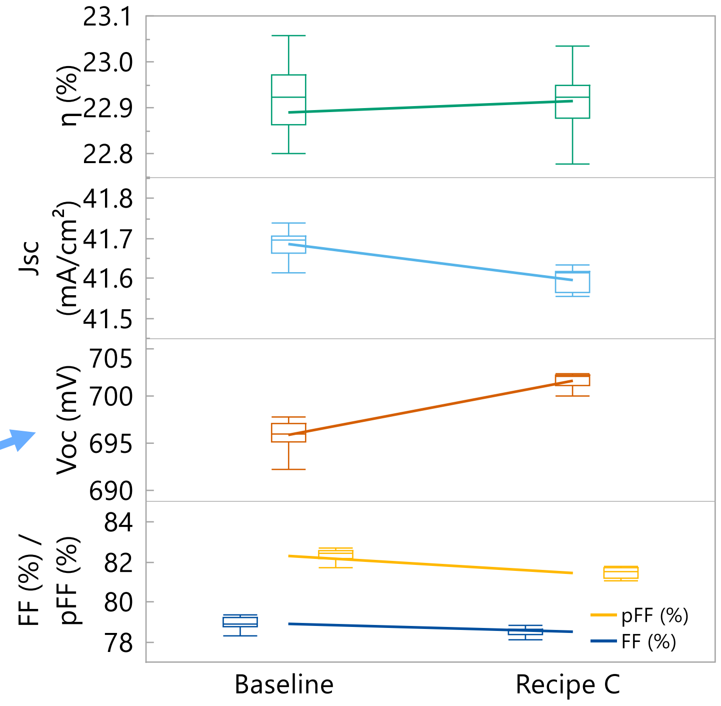


Lower J_0 in gap/frontside for recipe C

Area fraction gap/frontside: ~55%
→ Lower J_0 on precursors

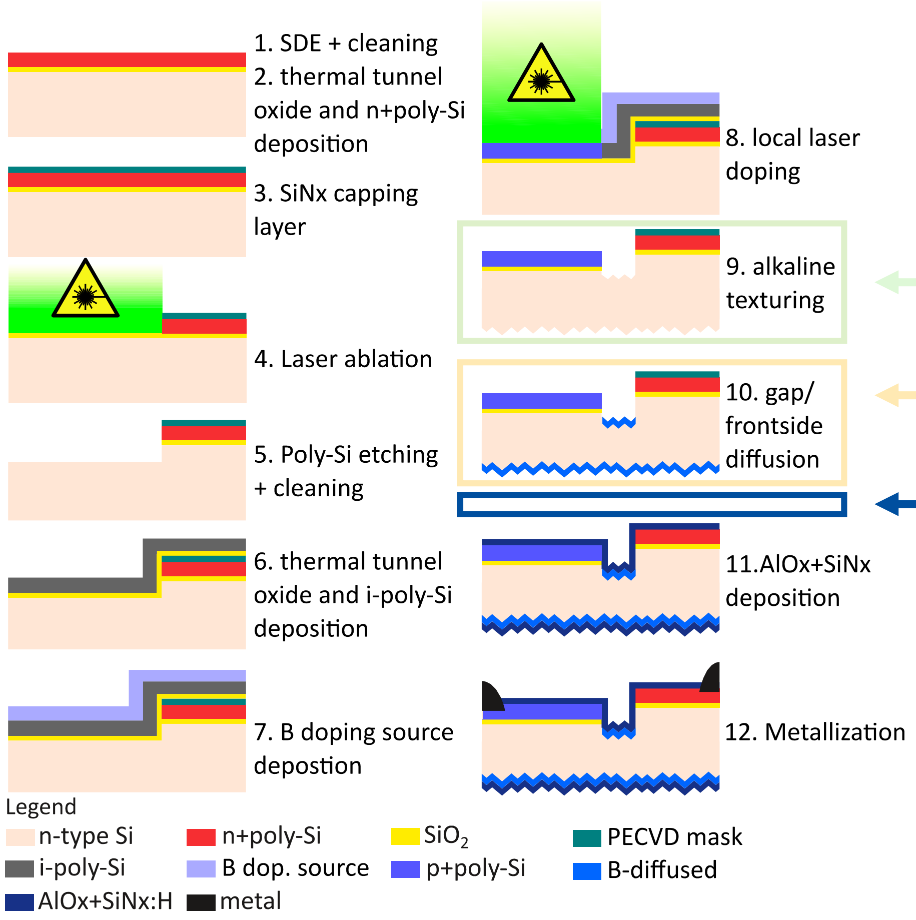
Consequently higher V_{oc}
(but similar η due to lower pFF)

polyZEBRA cells:



[6] Buchholz, F., Linke, J. et al., *Proc. WCPEC-8:* to be published

polyZEBRA process flow



9: Etch resistance of laser-treated p^+ poly-Si in alkaline solution

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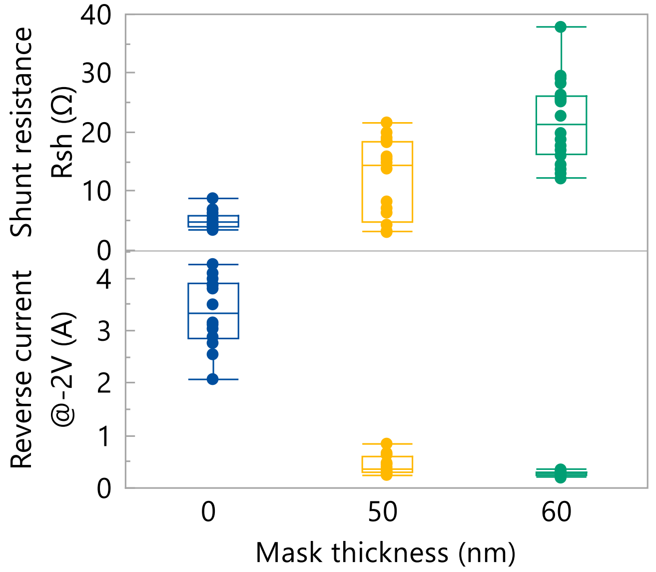
Between 10/11: Remove or retain SiN_x mask protecting n^+ poly-Si?

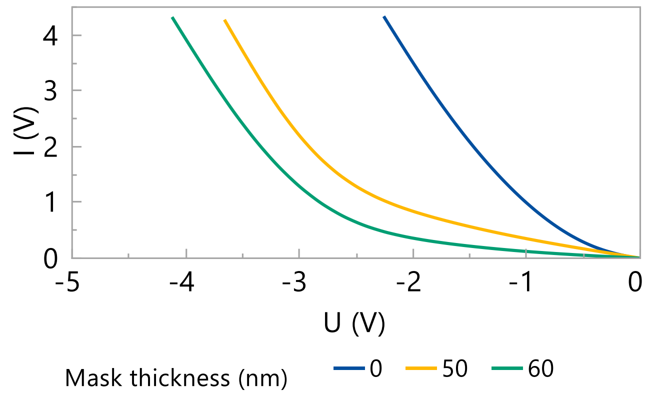
Remove or retain SiN_x mask protecting n^+ poly-Si?

Background: Mask removal would be one extra process step

Reverse bias characteristics of polyZEBRA cells:

- Shunt resistance reduces with thinner mask
- Early breakdown with non-diode behaviour after mask removal (0 nm thickness)
  → Mask blocks shunting
  → Mask mandatory for soft breakdown

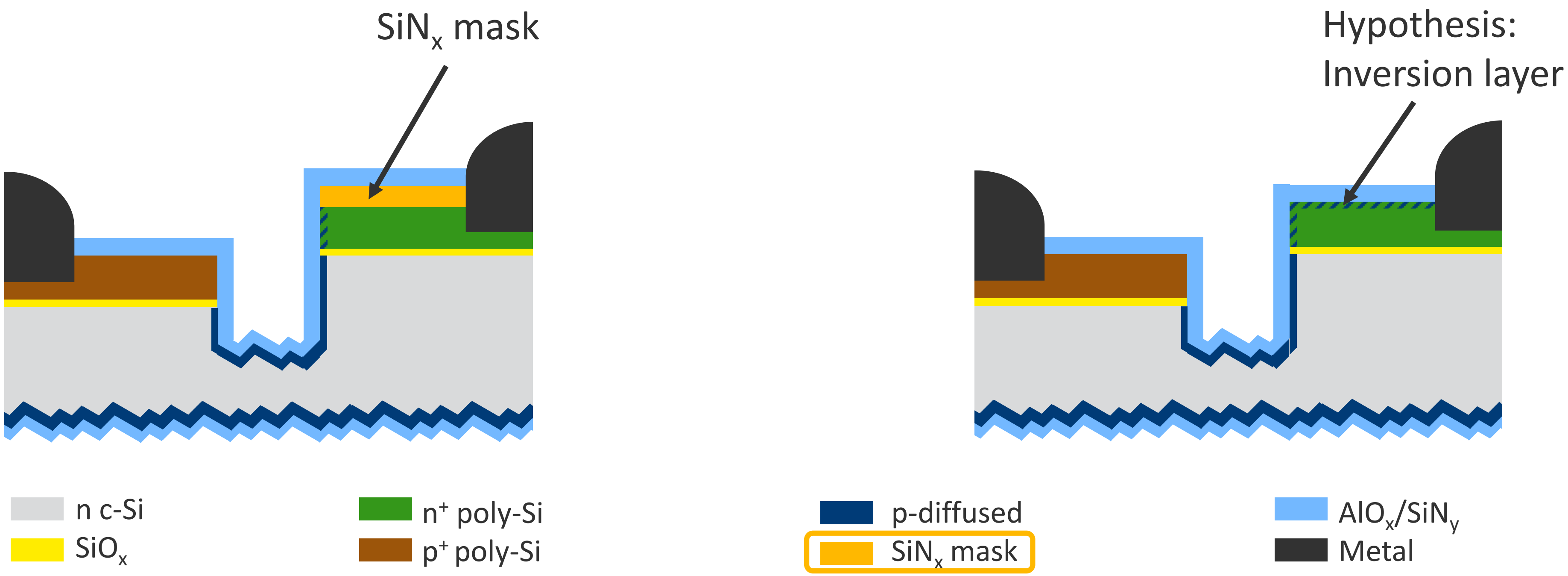




[5] Linke, J. et al., *Silicon PV* (2022): to be published

Remove or retain SiN_x mask protecting n^+ poly-Si?

Mask retaining | **Mask removal**

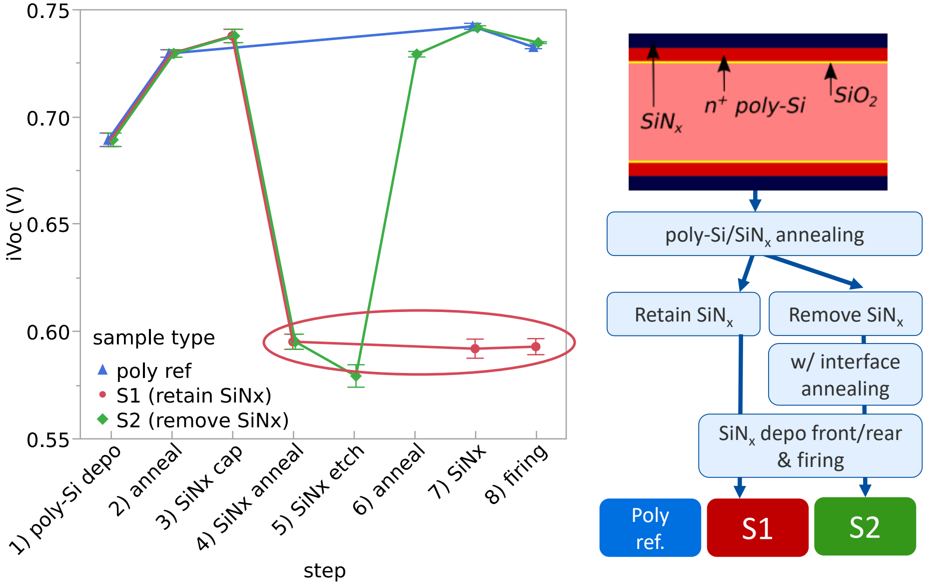


Conclusion: Mask retaining is beneficial

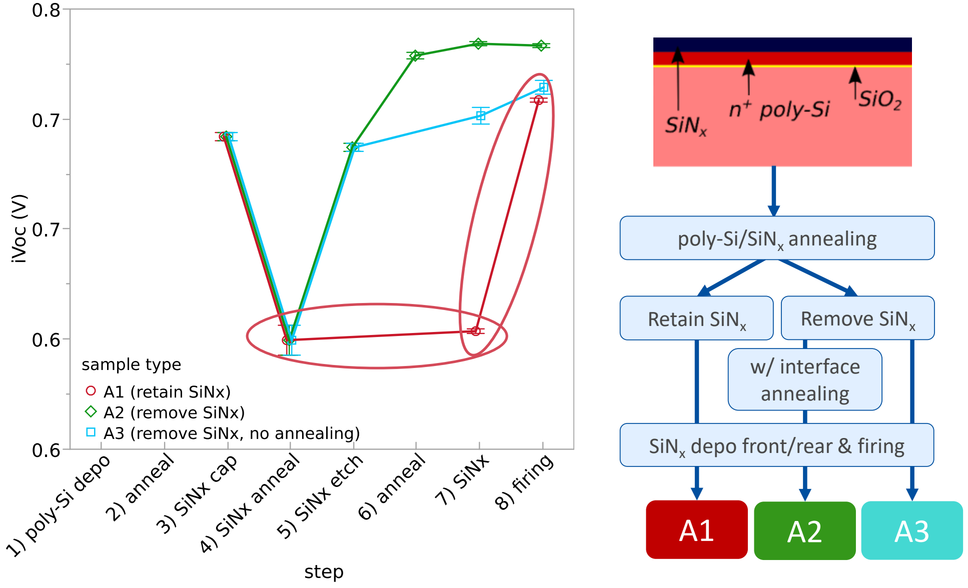
[5] Linke, J. et al., *Silicon PV* (2022): to be published

Remove or retain SiN_x mask protecting n^+ poly-Si?

Symmetric lifetime samples



Asymmetric lifetime samples

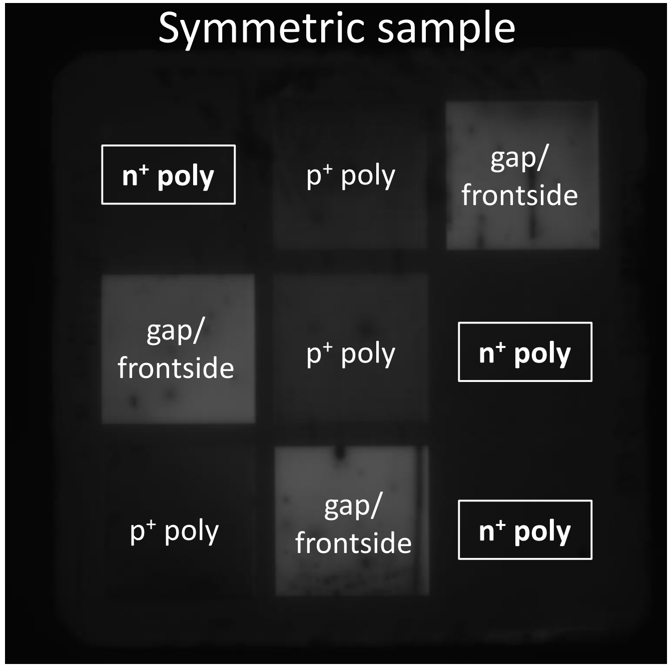


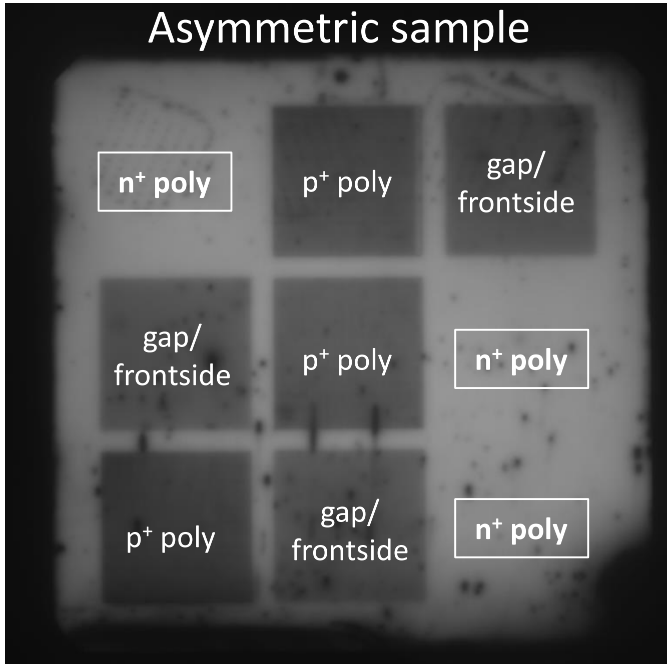
- SiN_x/n^+ poly-Si stacks degrade during tube furnace anneal to ~600mV (all groups)
- Recovery possible by SiN_x etch + 2nd tube anneal (S2,A2) *or* by firing of asymmetric lifetime samples (A1)
- polyZEBRA cell structure matches asymmetric lifetime samples A1 → **Mask retaining possible?**

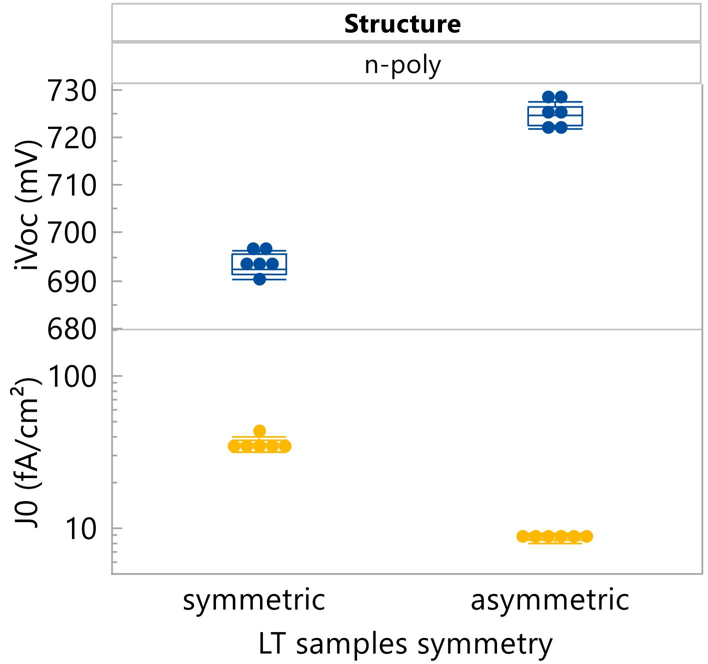
[8] Hoss, J. et al., *Proc. WCPEC-8:* to be published

Remove or retain SiN_x mask protecting n^+ poly-Si?

- Lifetime samples according to polyZEBRA cell process with SiN_x mask retained:



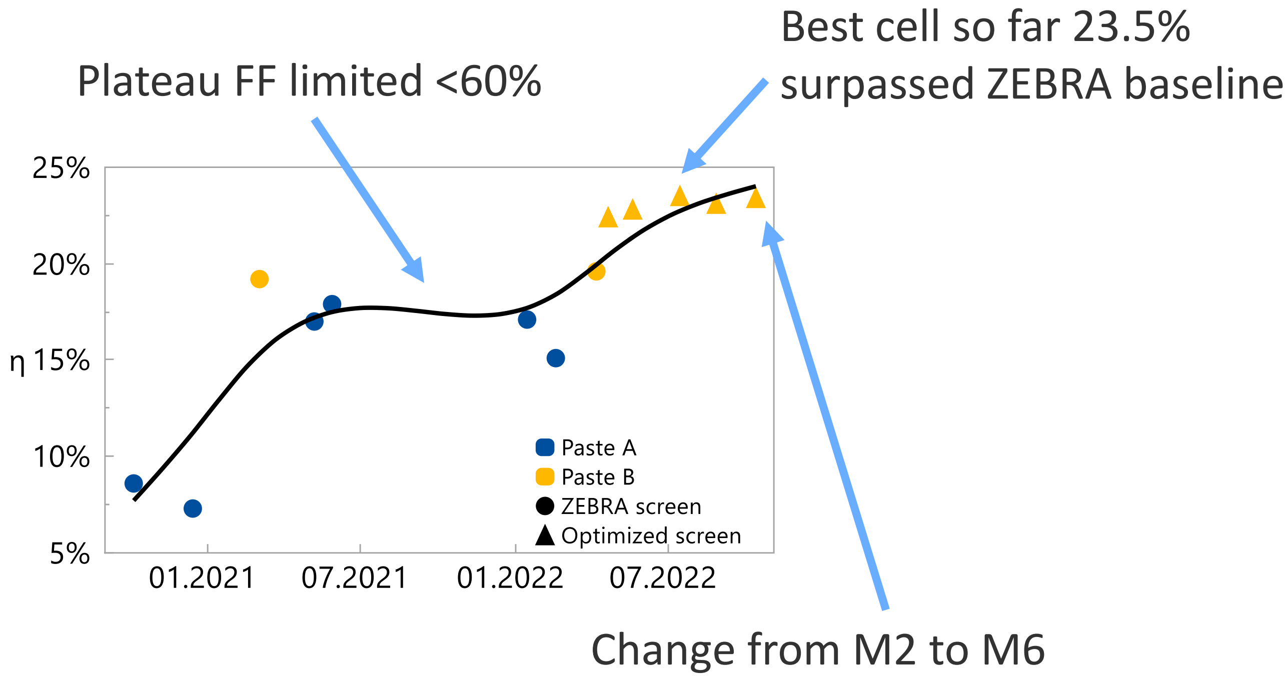


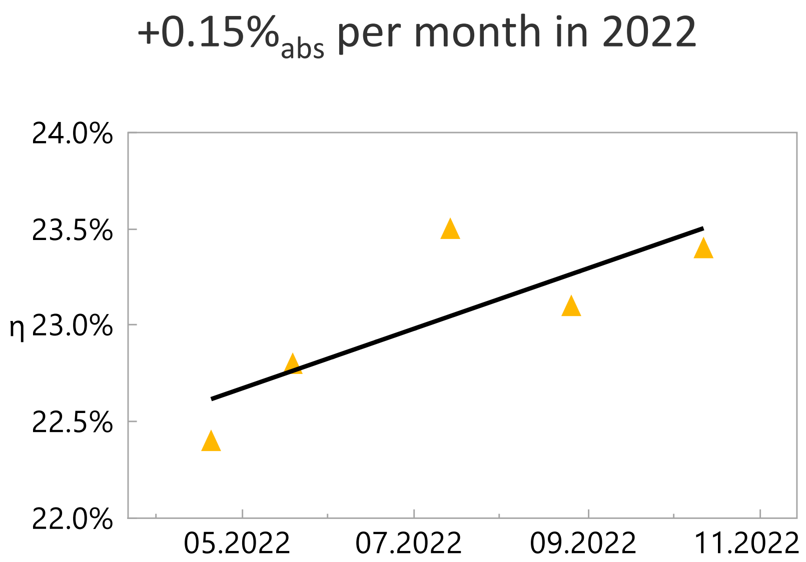


- Degradation of symmetric samples and recovery of asymmetric samples confirmed for cell process

Asymmetric samples match cell structure → polyZEBRA cells not affected → Mask will be retained in future

Learning curve





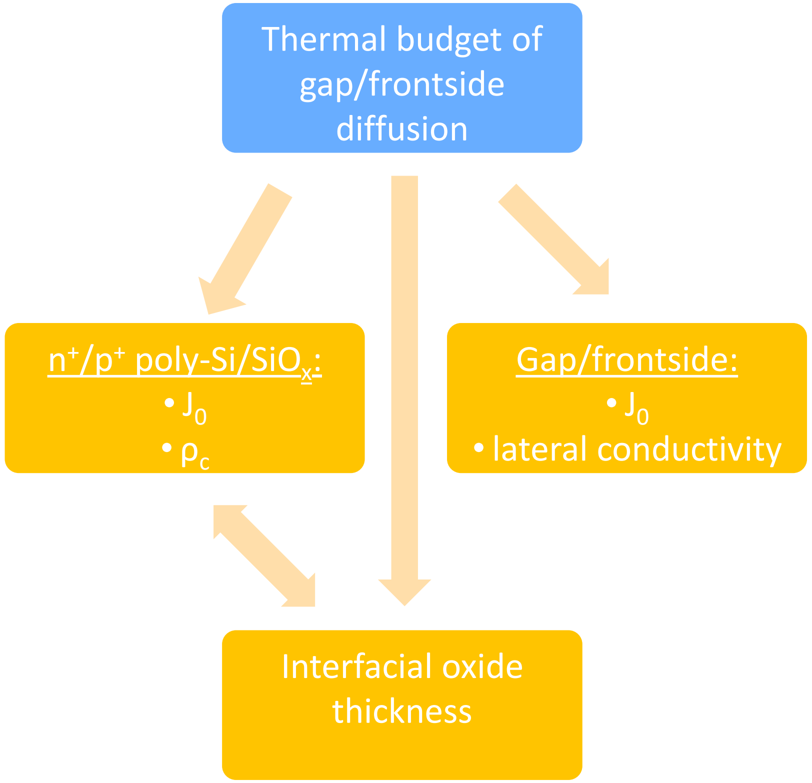
→ Reaching 25% in autumn 2023 ☺

Current champion cell on full-area M6 wafer format:

η (%)	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	pFF (%)	iV_{oc} (mV)	iV_{oc}-V_{oc} (mV)	pFF-FF (mV)
23.4	703	41.9	79.3	82.3	712	9	3

Challenges and next steps

- V_{oc} / pFF limited
- Co-optimization of p-diffusion for gap/frontside and p^+/n^+ poly-Si/SiO_x:
  - Gap/frontside J_0
  - Gap/frontside lateral conductivity (soft breakdown)
  - Thermal budget for n^+/p^+ poly-Si passivation (J_0)
  - Interfacial oxide thickness (J_0/ρ_c)
- Replace LPCVD poly-Si deposition by PECVD
- Replace BBr_3 ex-situ doping of p^+ poly-Si by in-situ doped PECVD p^+ a-Si or BSG / i a-Si stacks
- Fine-tuning (optical management, n^+/p^+ poly-Si and gap width, metallization, Ag reduction, …)



polyZEBRA – A both polarity passivating contact IBC cell, BC Workshop 2022, Konstanz

ISC research for a sunny future

Thank you for your attention

Acknowledgement:
This project has received funding from the European Union's Horizon2020 Programme for research, technological development and demonstration under Grant Agreement no. 857793.

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