Department of Materials

Electronic and Interface Materials Laboratory

UNIVERSITY OF OXFORD

A Failure Mode Affecting the Reliability of LECO-Treated High-Efficiency TOPCon Solar Cells

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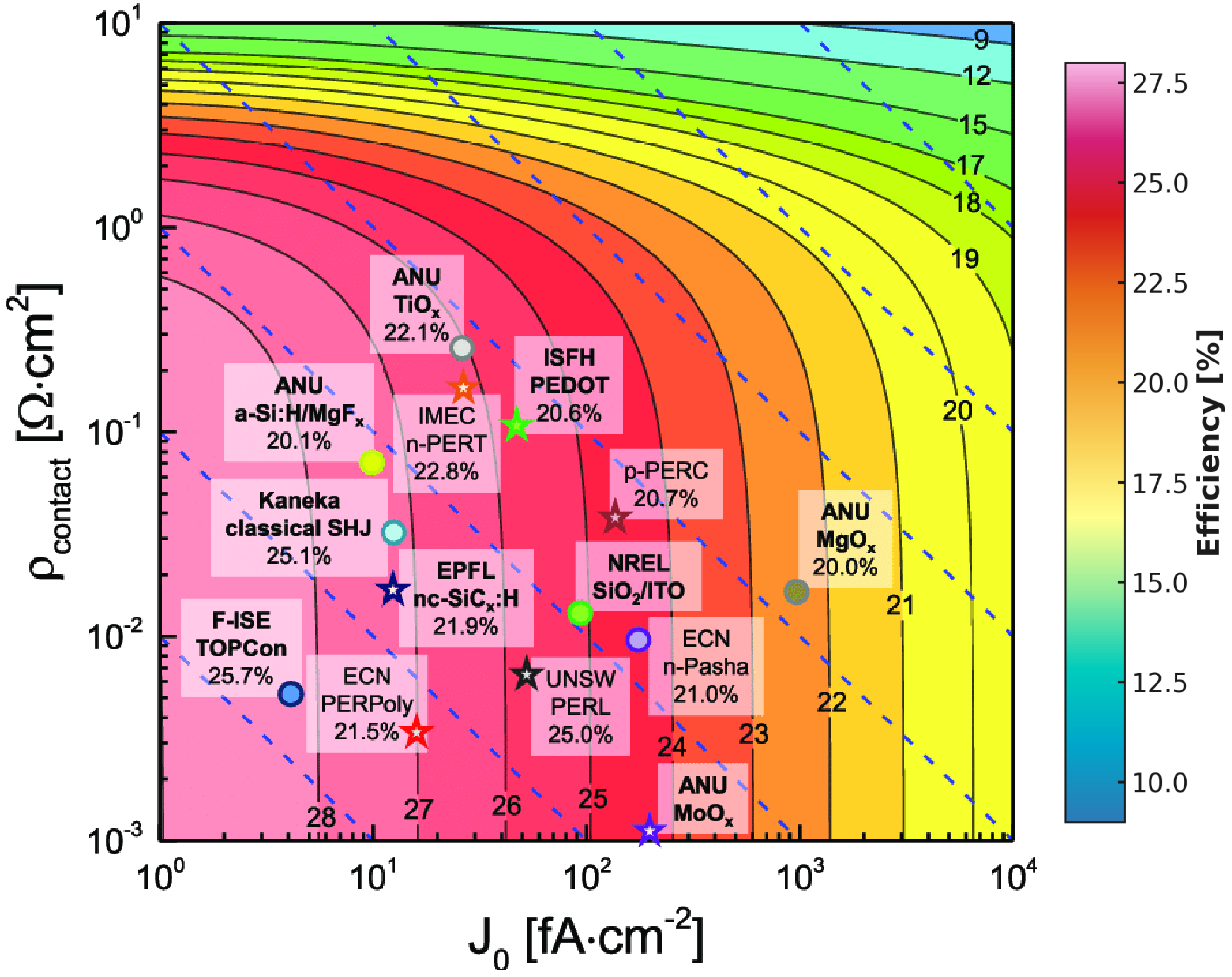
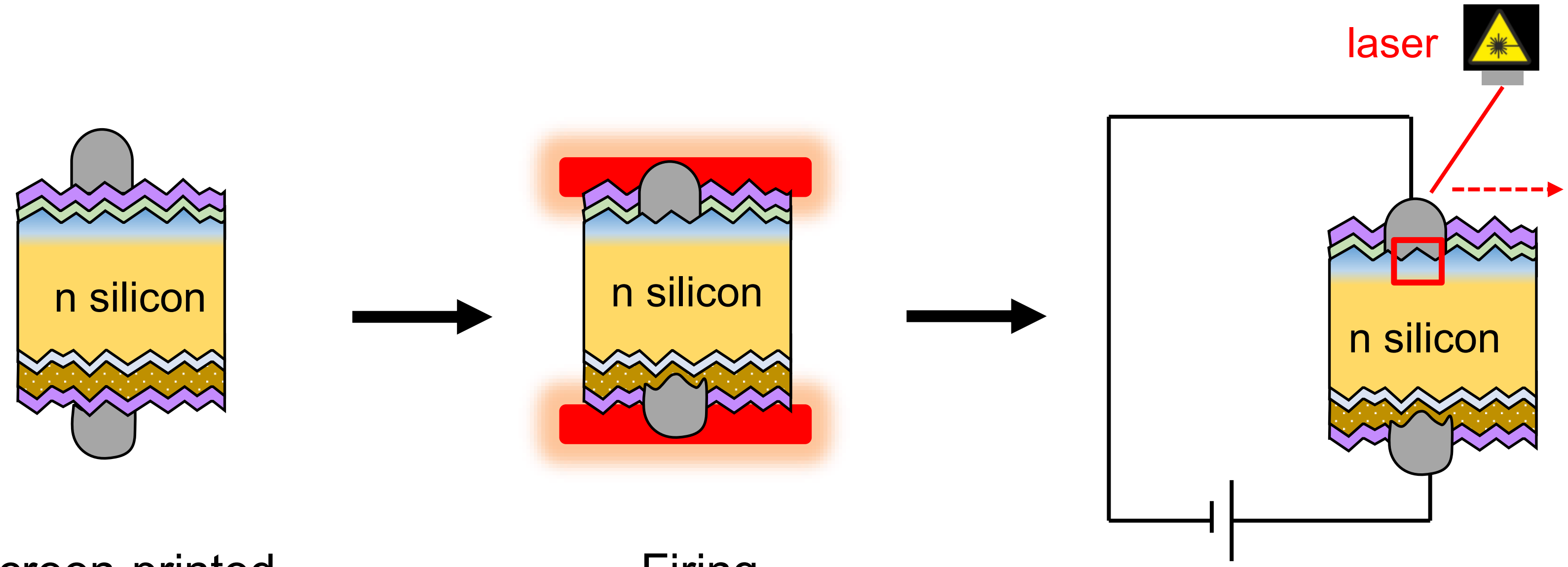
Metal-Semiconductor Contact



J. Melskens *et al.*, *IEEE J. Photovolt.*, vol. 8, no. 2, pp. 373–388, 2018. doi: 10.1109/JPHOTOV.2018.2797106.

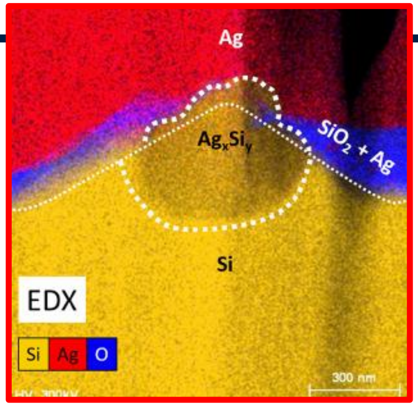
Laser Enhanced Contact Optimisation (LECO)



Screen-printed solar cells (LECO paste)

Firing (750 °C – lower than standard firing)

LECO: Bias applied while laser scans across the sample



LECO enables Si-Ag interdiffusion, forming sub-µm ohmic silicide contacts.

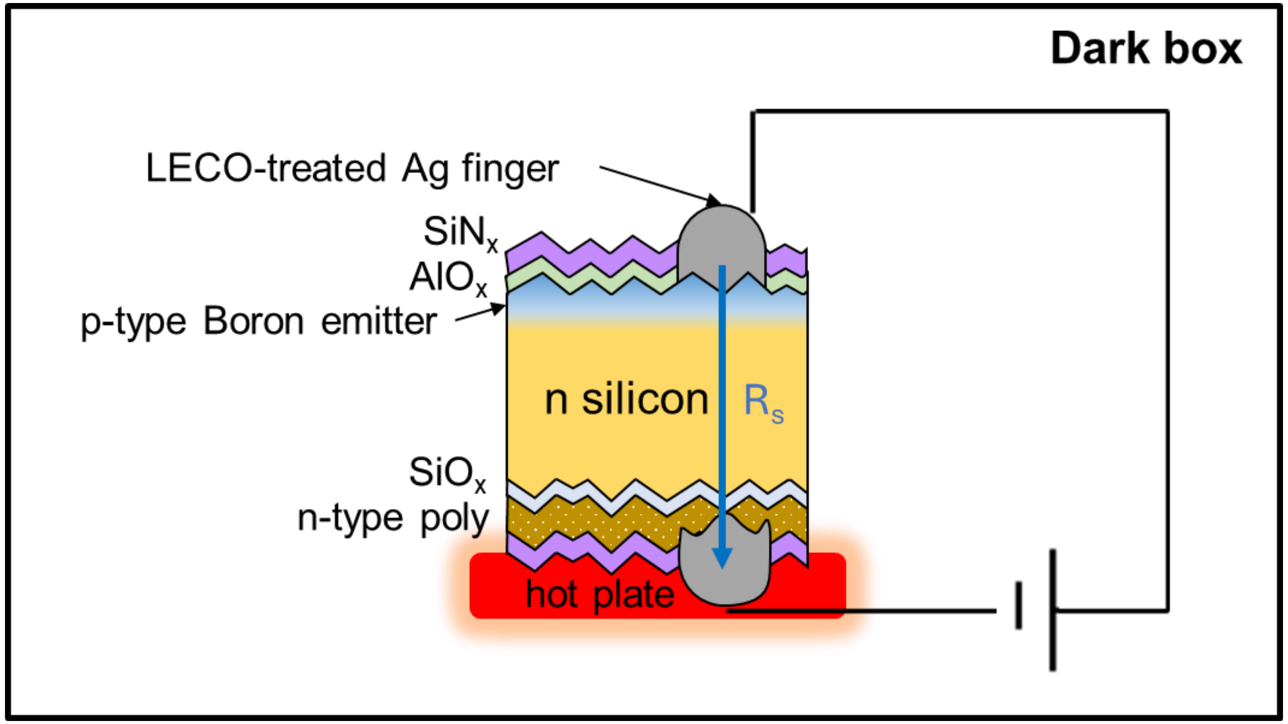
- η: + 0.26 % abs
- ρ_c: < 1 m$\Omega \cdot$cm^2
- $J_{0,metal}$: 200 fA/cm^2

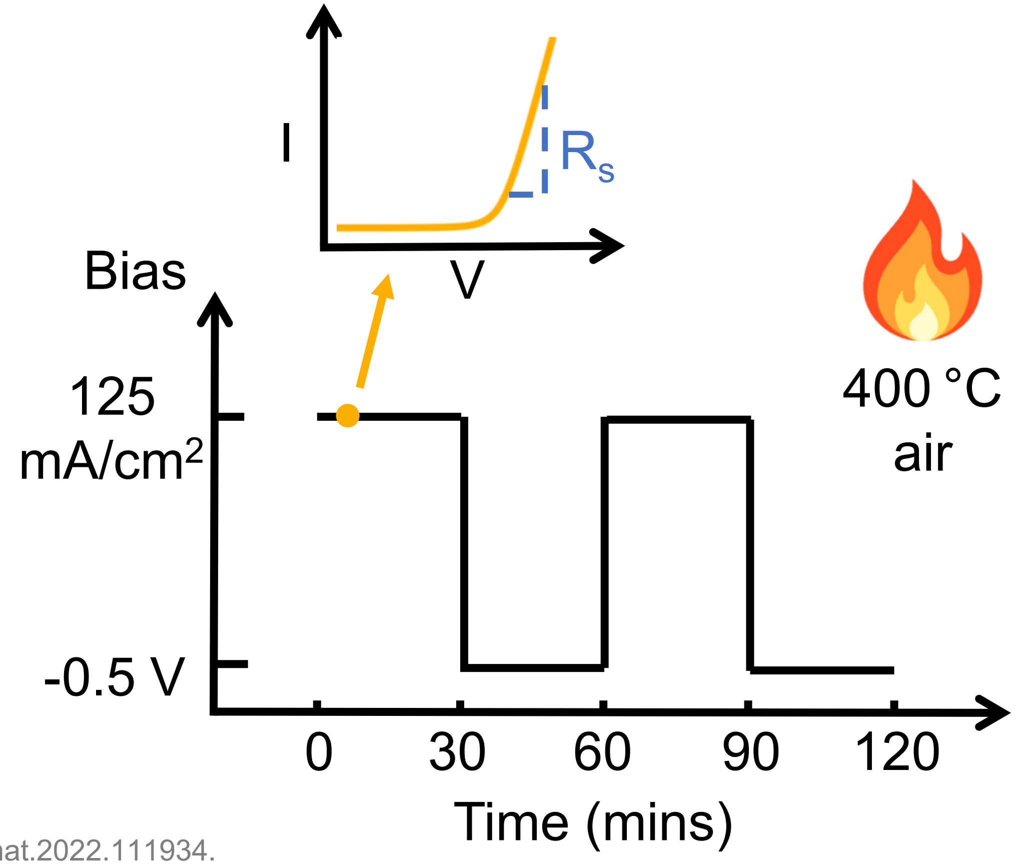
S. Groser *et al*., *IEEE J. Photovolt.*, vol. 12, no. 1, pp. 26–30, 2022. doi: 10.1109/JPHOTOV.2021.3129362.
Q. Wang, et al. , *Progress in Photovoltaics: Research and Applications*, 2024, doi: 10.1002/pip.3854.

Reliability Challenges in LECO-Treated Cells

Experimental setup

Measurement of series resistance degradation in LECO-treated cells under bias and temperature stress.



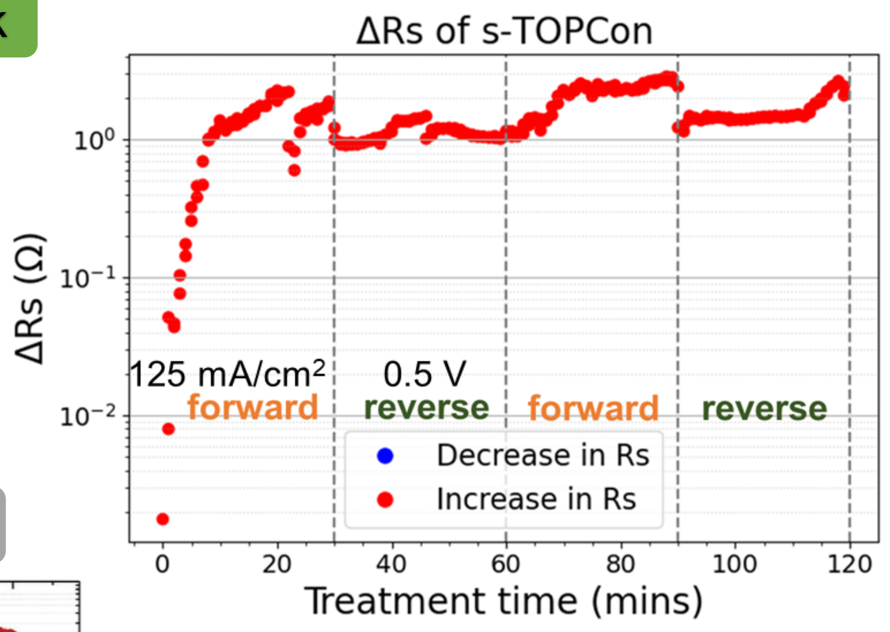


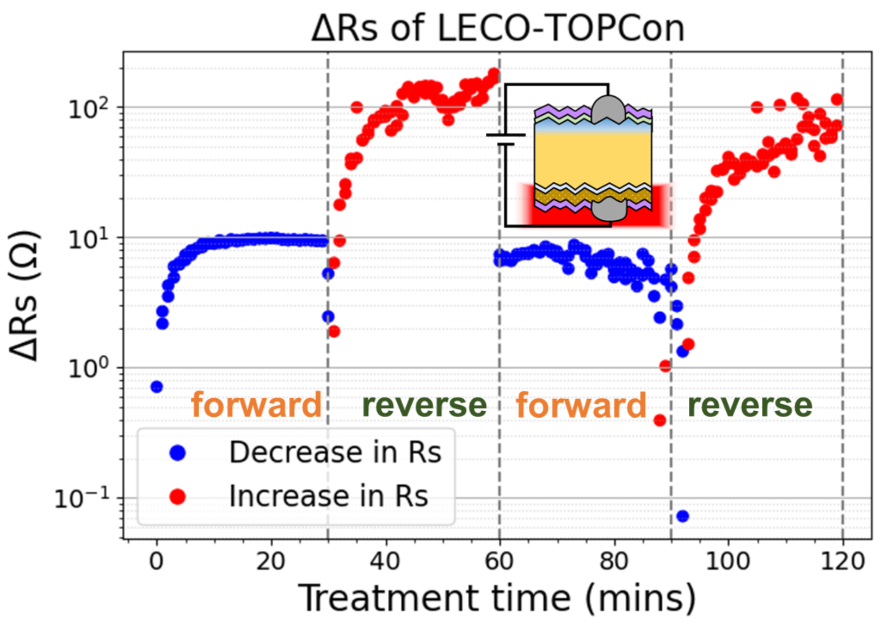
Method adopted from D. Liu et al., *Solar Energy Mater. Sol. Cells*, vol. 246, p. 111934, 2022. doi: 10.1016/j.solmat.2022.111934.

Standard TOPCon VS LECO-treated TOPCon

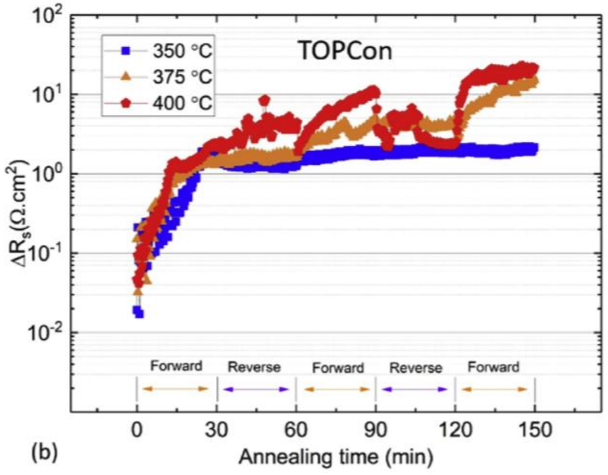
s-TOPCon: standard TOPCon
LECO-TOPCon: LECO treated TOPCon

Bias + 400°C + dark





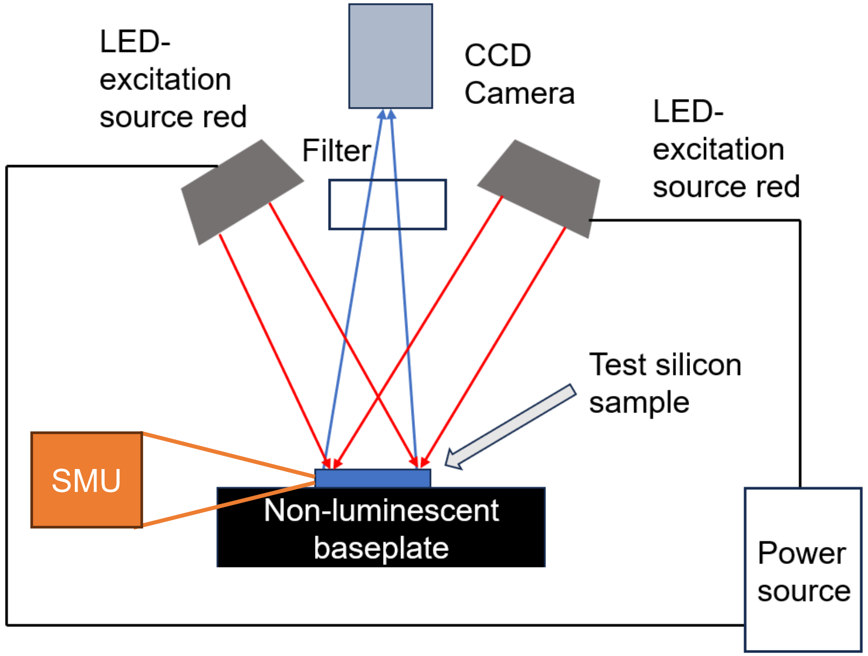
Literature support

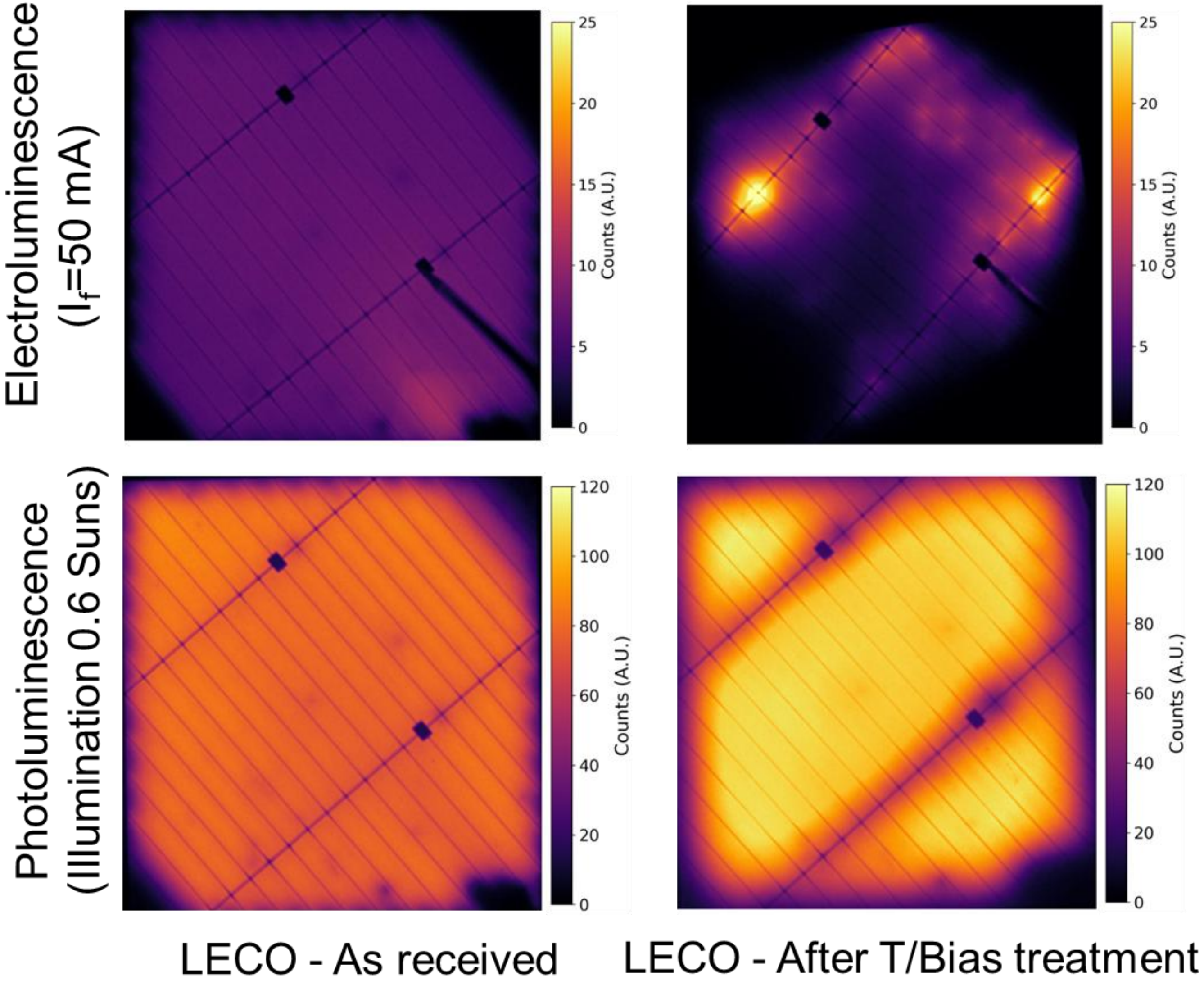


Contact resistivity ρ_c ($m\Omega \cdot cm^2$)	s-TOPCon (front)	LECO – TOPCon (front)
Before Treatment	9.6	7.6
After Treatment	10.4	511.2

D. Liu *et al.*, *Sol. Energy Mater. Sol. Cells*, vol. 246, pp. 111934, 2022. doi: 10.1016/j.solmat.2022.111934
Published in: Y. Xiong *et al.*, *Solar RRL*, vol. 9, no. 12, 2025; https://doi.org/10.1002/solr.202500151

Electro- and Photo-luminescence

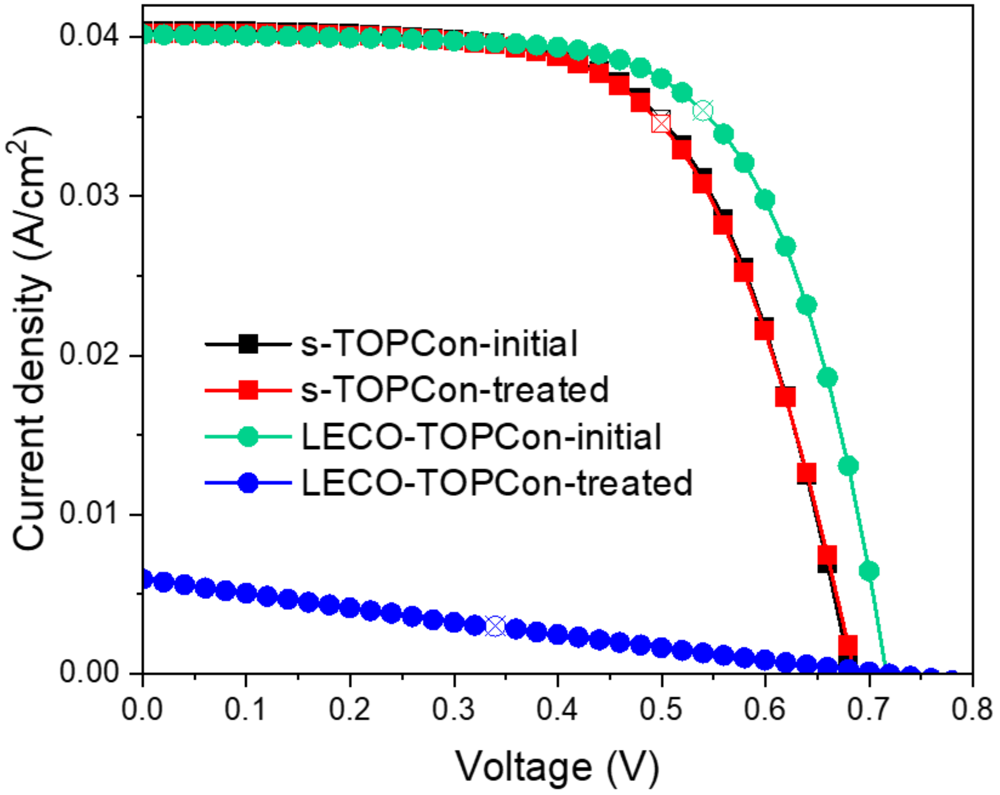




- **EL:** Overall **increase** in yield → increased series resistance.
- **PL:** Overall **increase** in yield → reduced recombination, improved passivation.

Device measurements

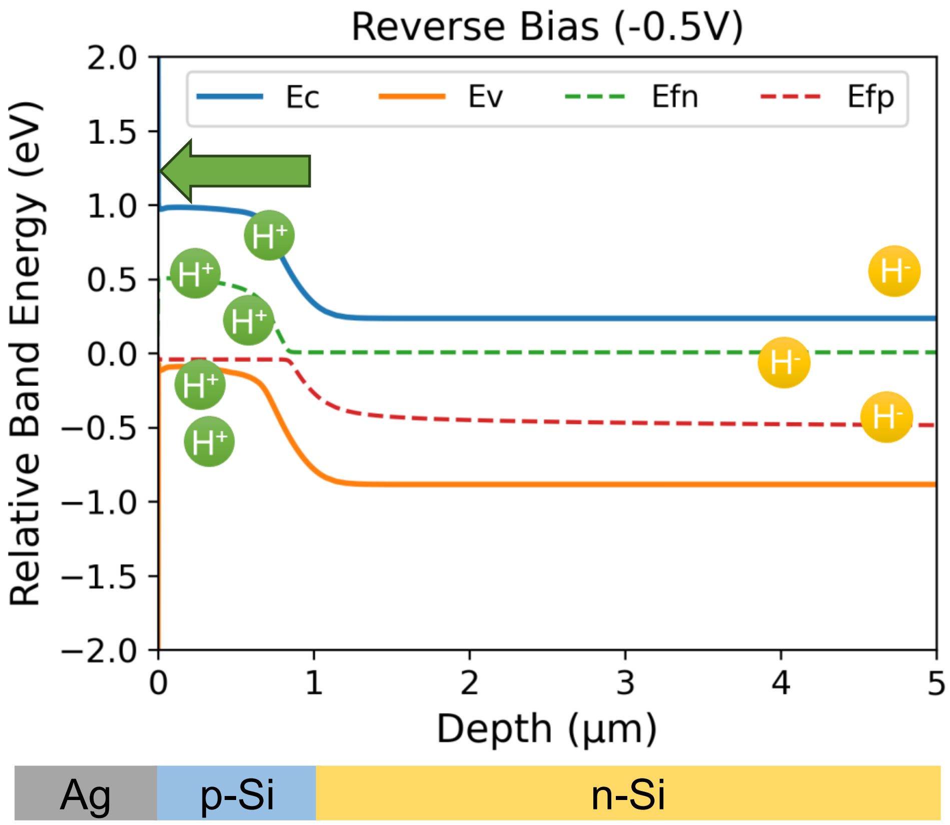
Treatment: reverse bias of 0.5V for 30 minutes at 400°C.

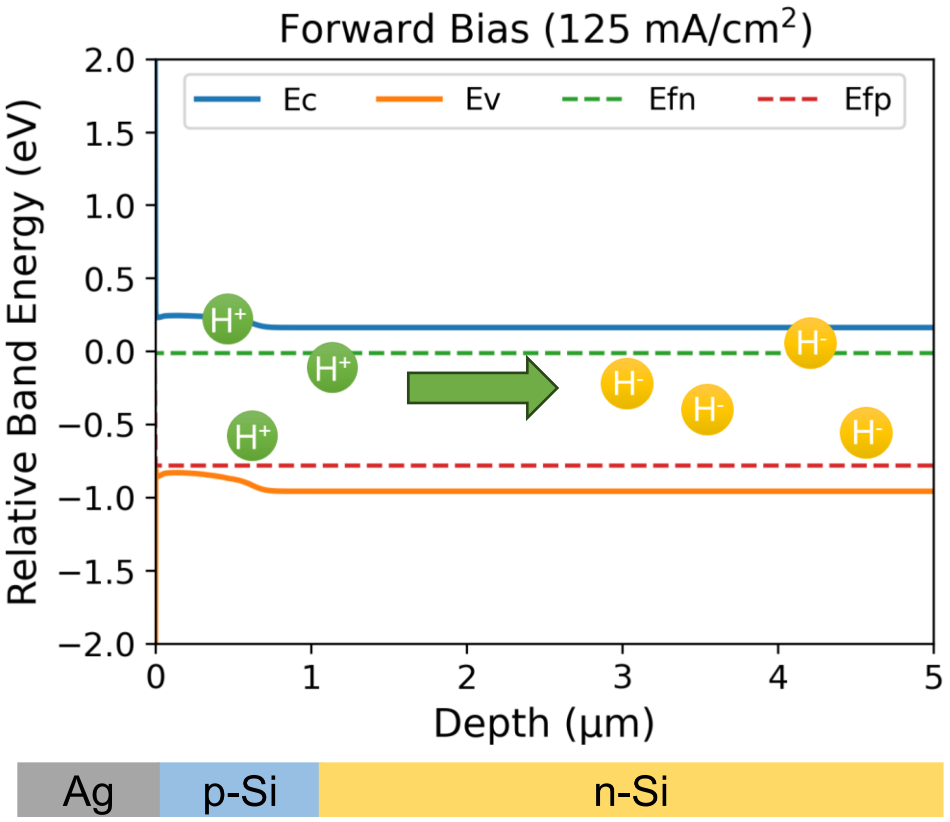


		V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
s-TOPCon	Initial	681.8	40.38	63.2	17.41
	Treated	685.6	40.22	62.6	17.26
LECO-TOPCon	Initial	716.6	40.16	66.3	19.09
	Treated	719.1	4.33	32.6	1.02

One possible hypothesis

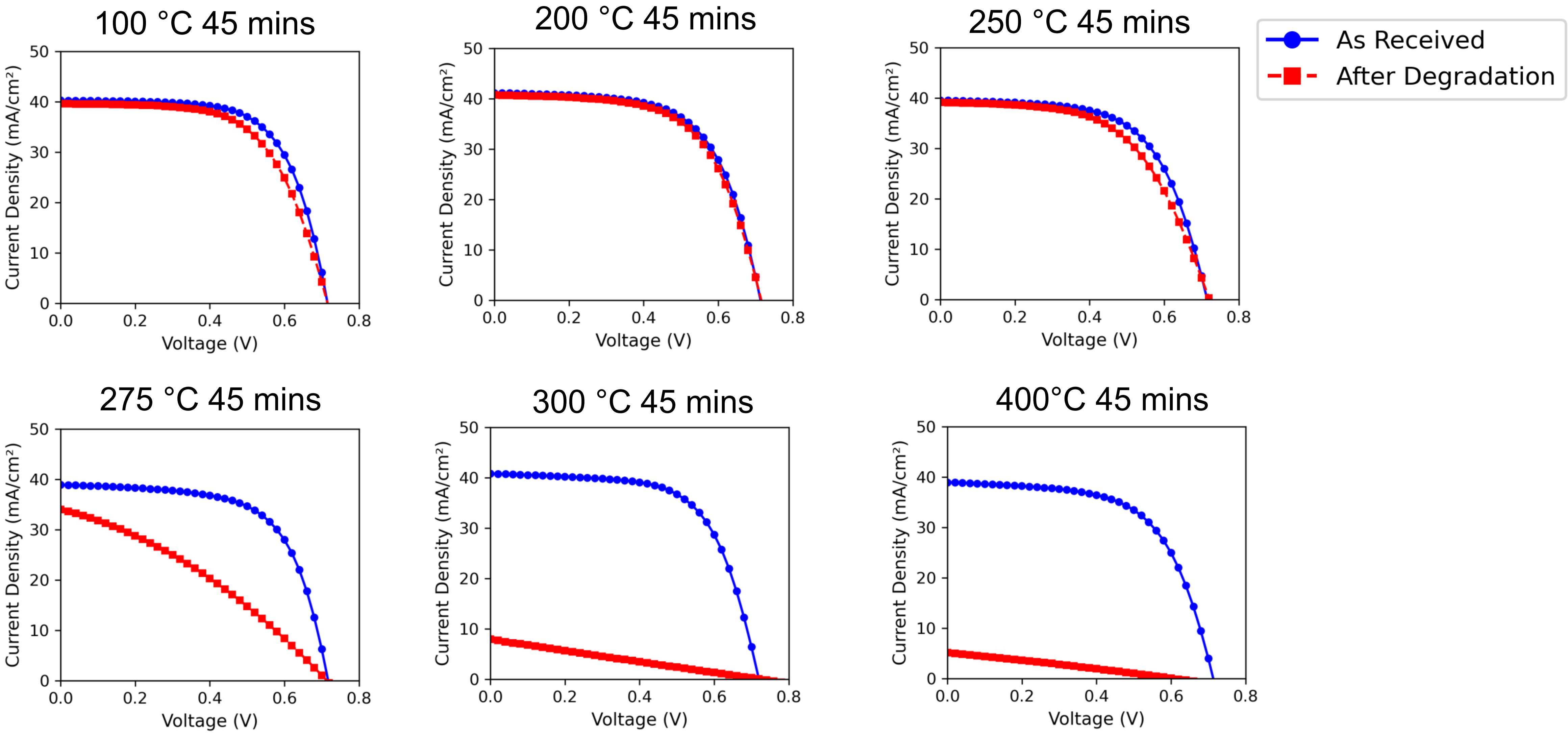
Simulated band diagram using Sentaurus:



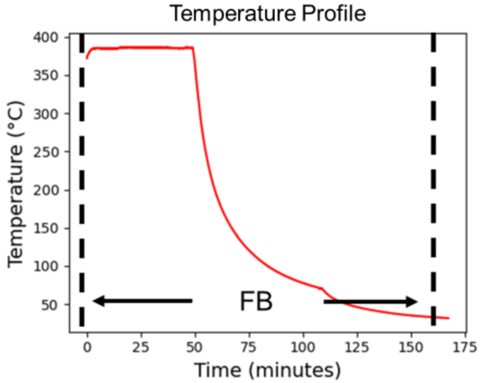


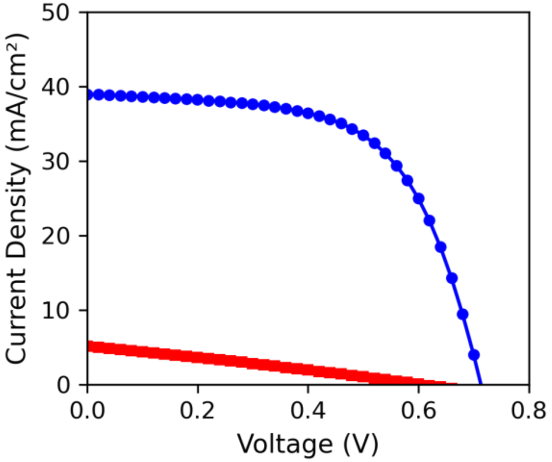
D. Liu *et al., Sol. Energy Mater. Sol. Cells*, vol. 246, pp. 111934, 2022. doi: 10.1016/j.solmat.2022.111934

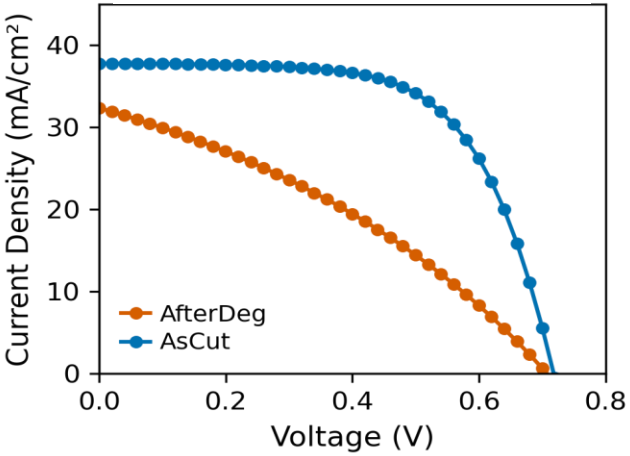
Activation energy for LECO degradation

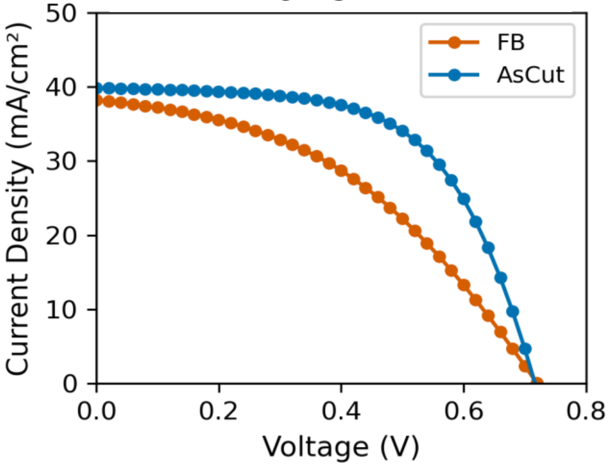


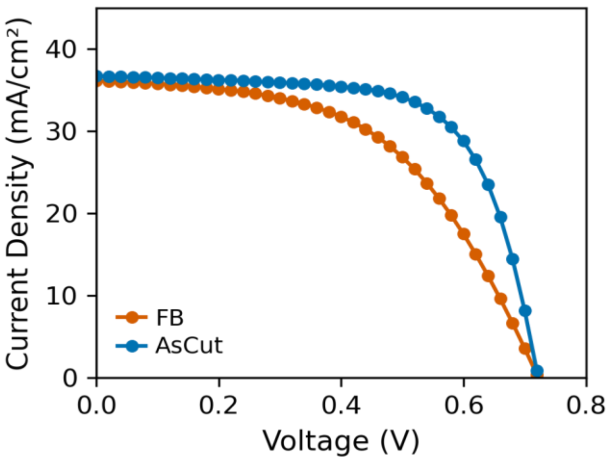
Forward bias improves IV stability at 400 °C











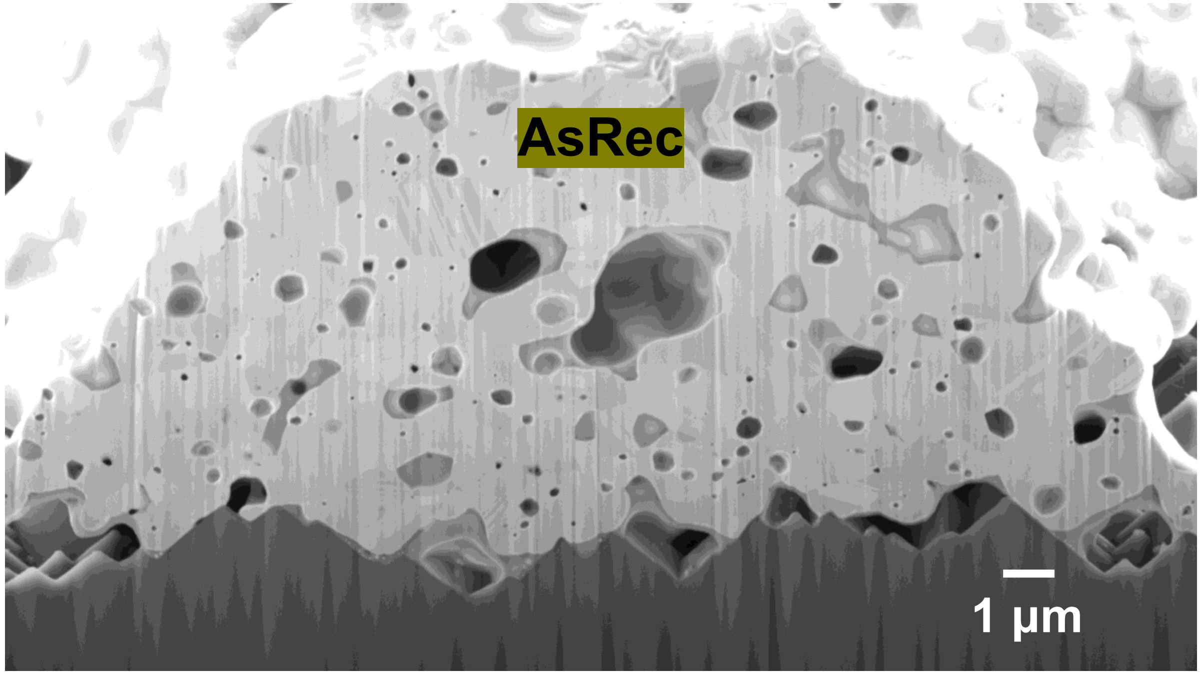
Condition	Jsc [mA/cm²]	Voc [mV]	FF [%]	Efficiency (eta) [%]
AsCut	37.81	719.36	63.41	17.25
FB 0.25A	32.37	707.75	34	7.79

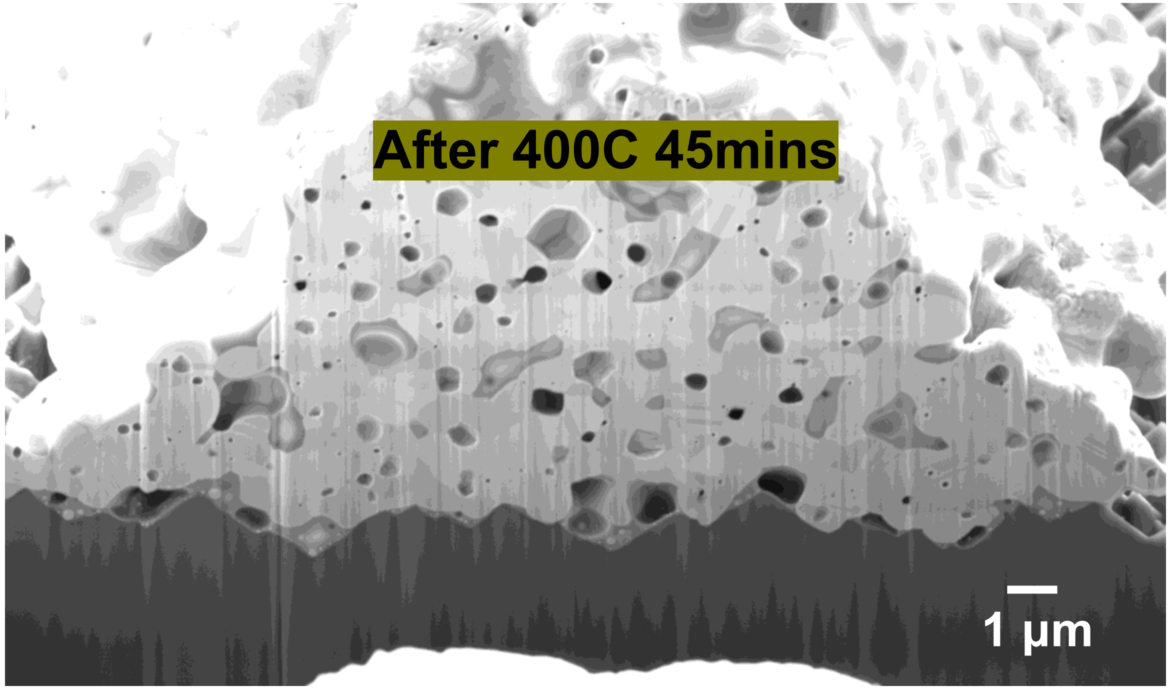
Condition	Jsc [mA/cm²]	Voc [mV]	FF [%]	Efficiency (eta) [%]
AsCut	39.36	715.95	64.14	18.07
FB 0.5A	38.23	717.12	43.9	12.04

Condition	Jsc [mA/cm²]	Voc [mV]	FF [%]	Efficiency (eta) [%]
AsCut	38.38	721.57	67.16	18.6
FB 1A	36.18	722.34	51.72	13.52

- Increasing forward bias during 400 °C anneal progressively reduces IV degradation by stabilising series resistance.

LECO-TOPCon EM Comparison





After annealing:

- **Pores shrink** → interface becomes more coherent.
- **More and larger Ag nanoparticles** are observed at the interface → may hinder carrier transport process.

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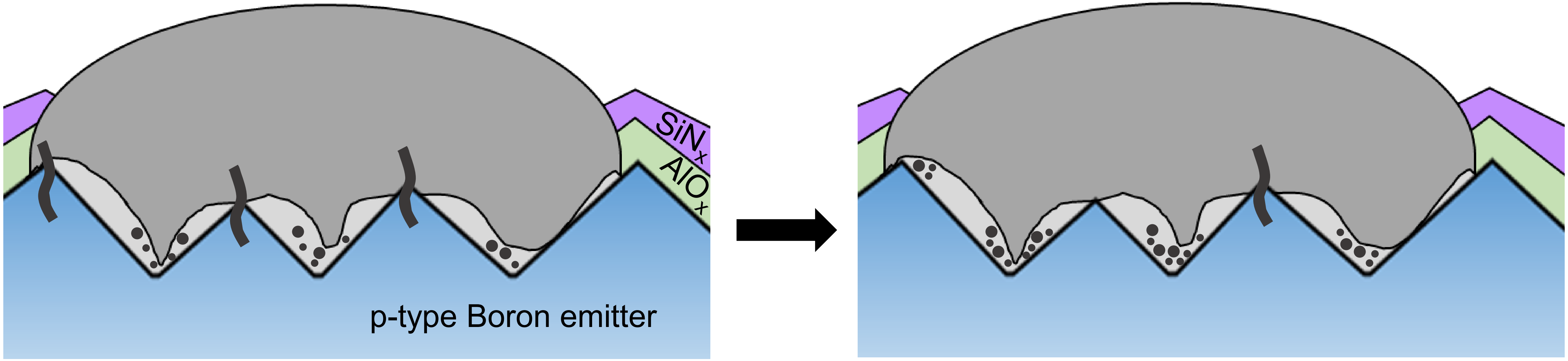
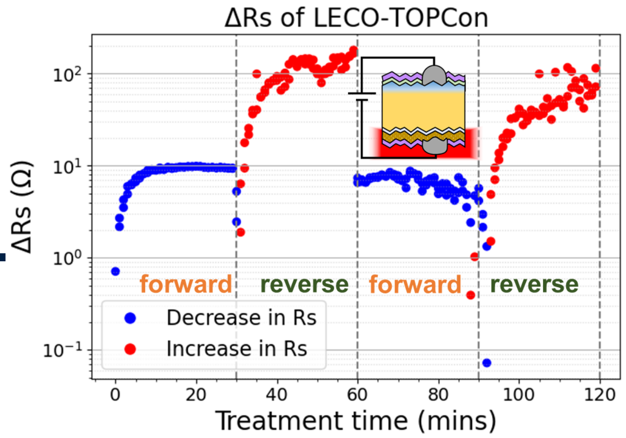
Another possible hypothesis

LECO (Laser + reverse bias -> local joule heating)
Conductive bridges can be formed at the Si-Ag interface (at the top of pyramids), ρc ↓

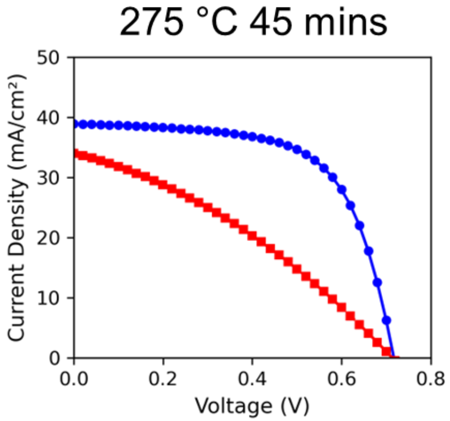
400°C dark anneal (no bias):
Capillarity/Ostwald ripening dominates → bridges neck down and pinch off, beads become rounder, more isolated → Rs ↑.

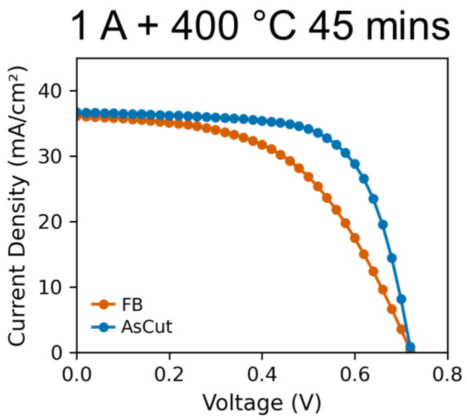


Conclusions



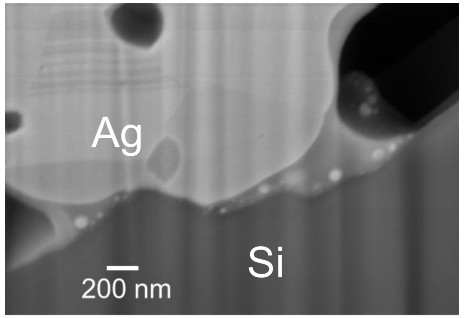
- Reverse bias at 400 °C increases R_s in LECO–TOPCon
- Hydrogen accumulation at p^+/Ag may degrade contact conductivity.
- IV degradation occurs even during unbiased annealing onsets at 275°C.
- Forward bias reduces this degradation by stabilising R_s.
- Ag–Si bridges may break into isolated colloids at high temperatures, increasing resistance.





Future Work

- Analyse degradation kinetics and mechanisms.
- Further correlate microstructure and electrical behaviour.



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