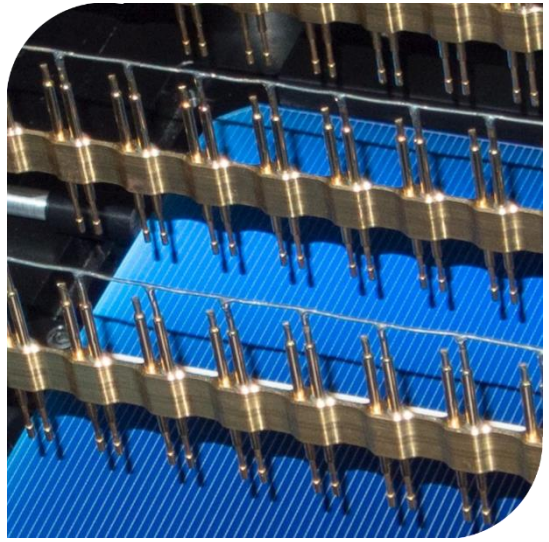



Cu Screen-Printed IBC/TBC Technology for a Sustainable PV Future

J. Linke[1], D. Rudolph[1], N. Chen[1], T. Meßmer[1], I. Rosen[2],

M. Grouchko[2], O. Shochet[2], A. Halm[1], F. Buchholz[1]

[1]ISC Konstanz e.V., Germany

[2]Copprint Technologies Ltd., Israel

ISC research for a sunny future

Copprint Powered

Agenda

- From ZEBRA (IBC) to polyZEBRA (TBC)
- Ag vs. Cu
- Ag replacement concepts in (poly)ZEBRA metallization
- Cu-(poly)ZEBRA cell result
- Cu-ZEBRA module reliability
- Cu-ZEBRA full-size module

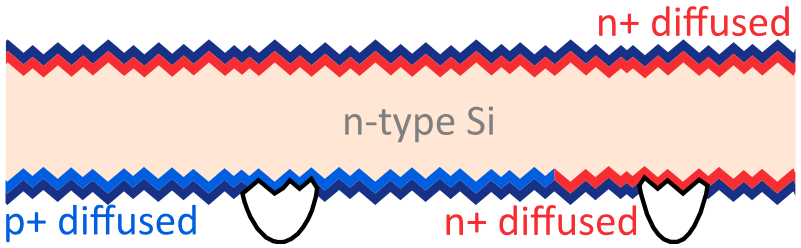
From ZEBRA to polyZEBRA

ZEBRA IBC

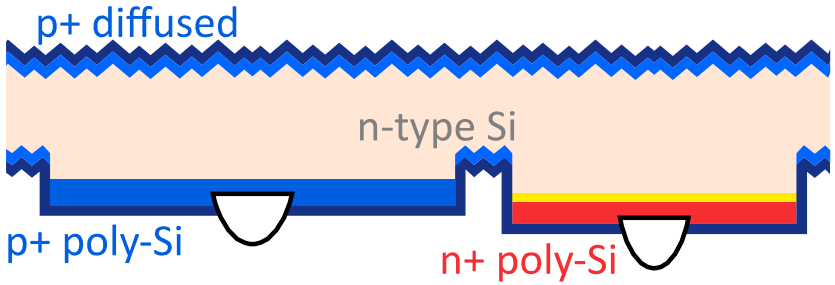
- PERC-like IBC cell
- p/n regions diffused
- Direct contact of p/n regions

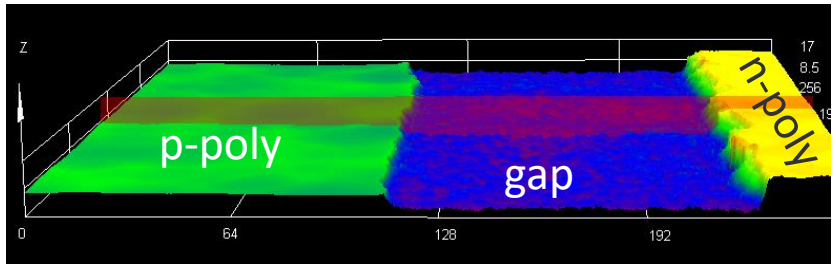
polyZEBRA TBC

- TOPCon-like IBC cell
- p/n regions poly-Si/SiO_x contacts
- Textured gap between p/n regions



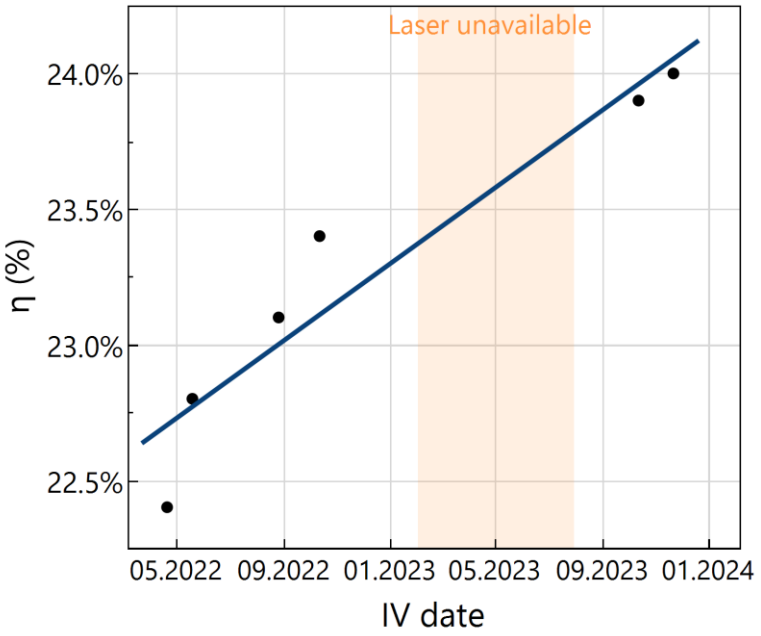
Upgrade

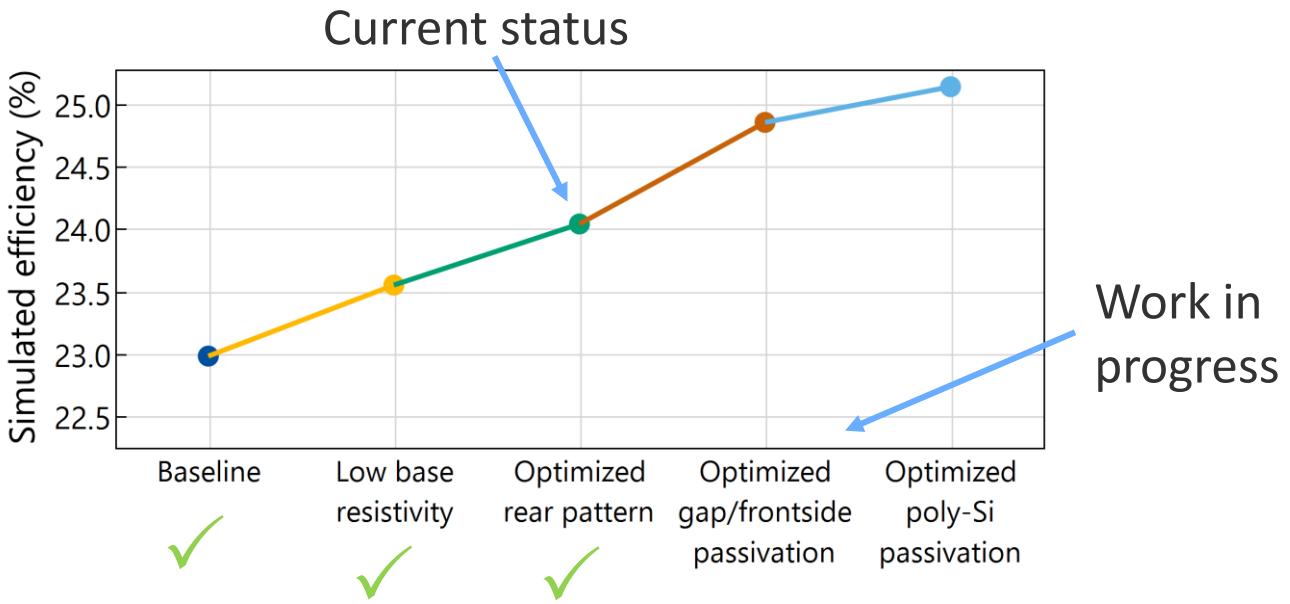




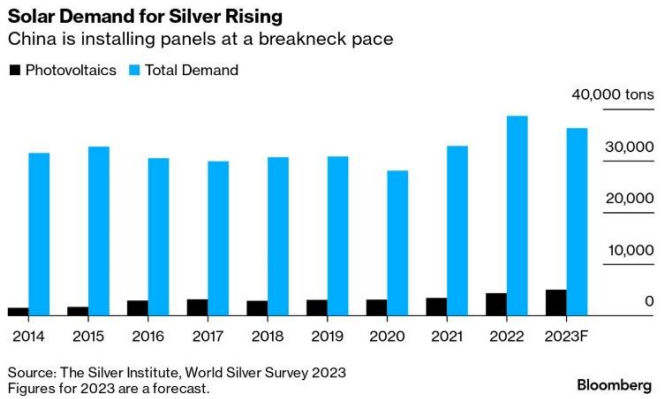
polyZEBRA roadmap to 25%

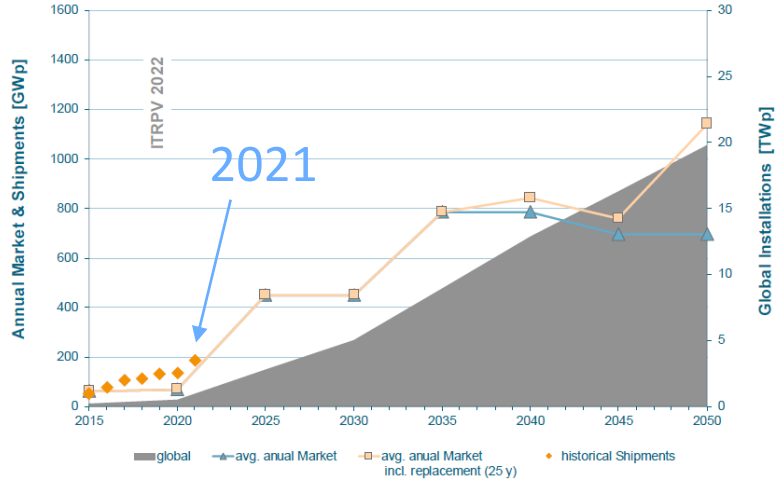
16 cells	η	Voc (mV)	Jsc (mA/cm²)	FF	pFF	iVoc (mV)
Champion cell	24.0%	710	41.7	80.9%	82.7%	/
Mean ± std	23.7% ± 0.2%	706 ± 2	41.6 ± 0.1	80.6 ± 0.3	82.3 ± 0.3	717 ± 0.2





Silver cannot be the solution





- Silver price high and volatile
- Ratio of PV silver demand to global silver demand steadily increasing
- Annual market expected to grow > 1 TWp/year (today ~200 GWp/year)

→ **Reduction/replacement of silver is mandatory**

Copper as replacement material

	Silver	Copper	Copper vs. Silver
Price ($/kg)	802	8.3	~100x cheaper (28.11.23)
Conductivity (10^{-8} Ωm)[1]	1.59	1.68	5% less conductive
Carbon footprint ($kgCO_2/kg$)[2]	155	3.97	40x better
Max level in drinking water (mg/l)[3]	0.1	1.0	10x less toxic
Abundance in Earth's crust (ppm)	0.08	68	~1000x more abundant

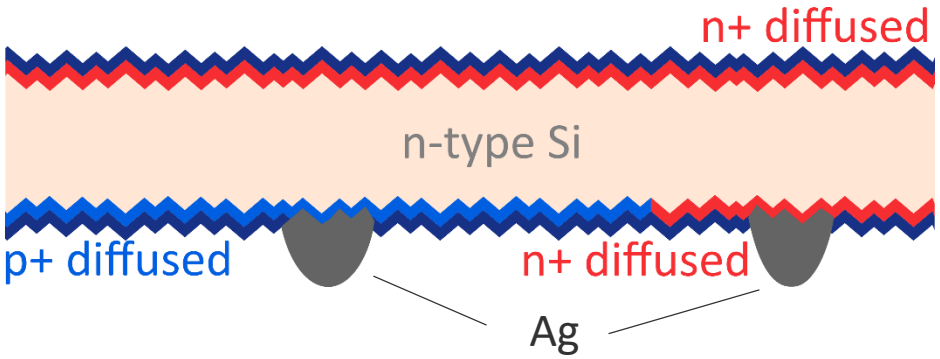
[1] W. M. Haynes, D. R. Lide, T. J. Bruno,, [Hrsg.]. CRC Handbook of Chemistry and Physics. Boca Raton, Florida : s.n., 2016-2017. S. 14-17. Bd. 97th edition.
[2] R. Schindler, N. Schmalbein, V. Steltenkamp, J. Cave, B. Wens, A. Anhalt,. SMART TRASH: Study on RFID tags and the recycling industry. 1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138 : Rand Corporation, 2012.
[3] https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals. [Online]

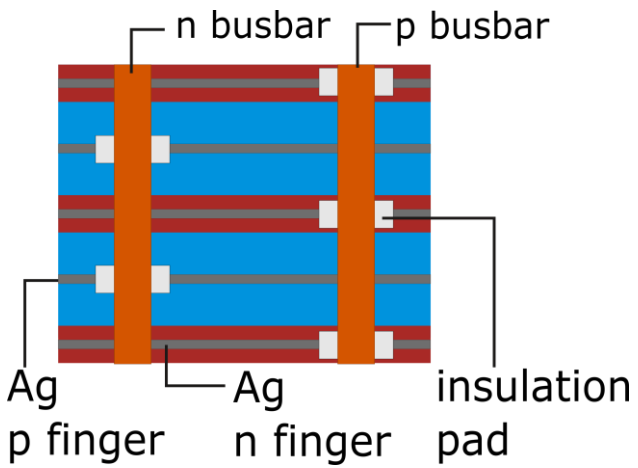
Screen-printed copper

- Technology well-known from PCB
- IBC ideal for Cu screen printing
- Compatible with standard PV equipment
- Curing fast and at low temperature:
  - “Snap curing” at 300°C
  - Few seconds with direct solid-to-solid heat transfer

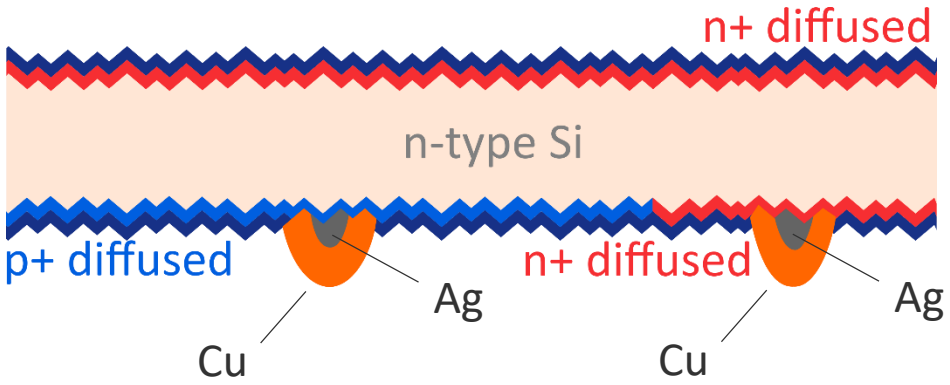
Ag replacement routes for (poly)ZEBRA IBC cells

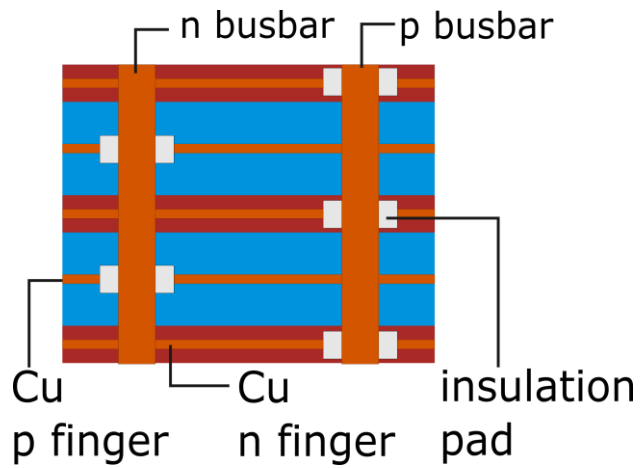
1. Replacement of **BBs** in ZEBRA





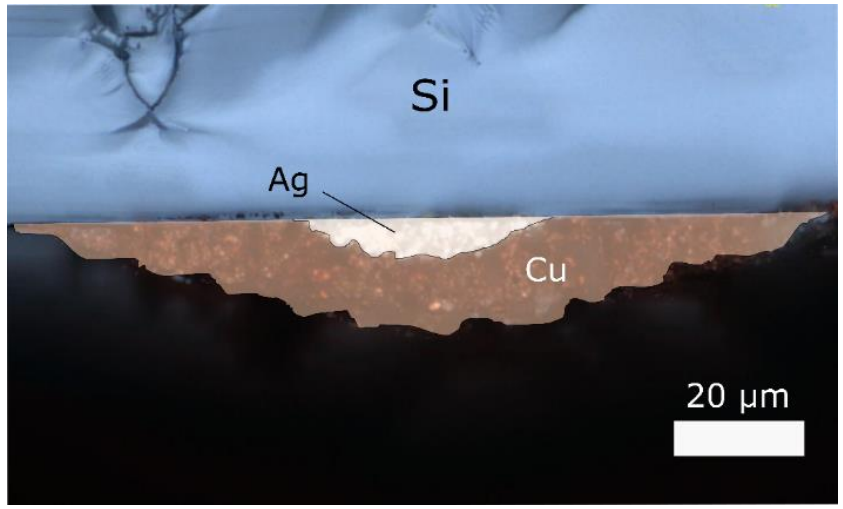
2. Replacement of **fingers** in ZEBRA



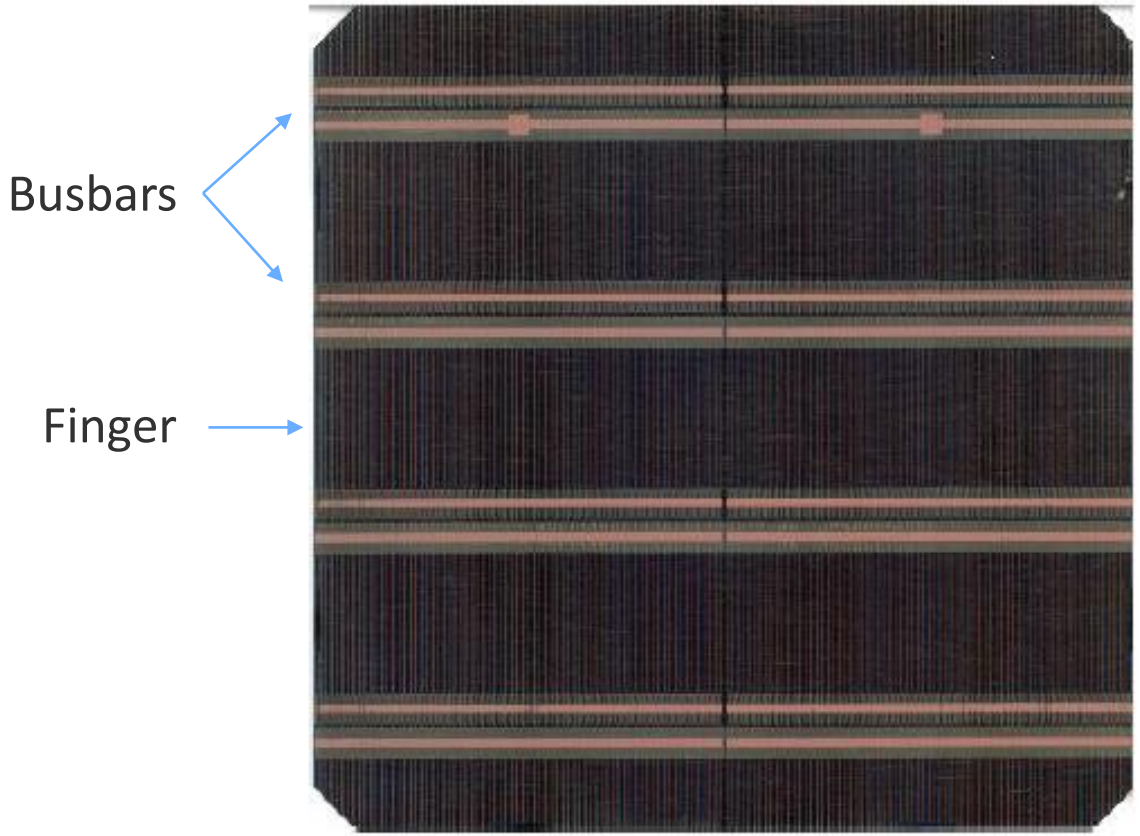


Cu-ZEBRA Cell

Ag seed layer for contact formation,
Cu finger for lateral conductivity

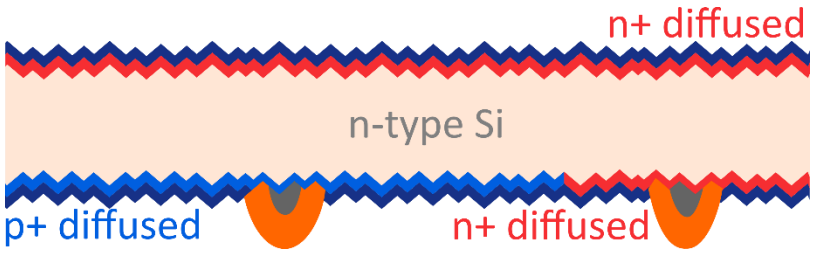


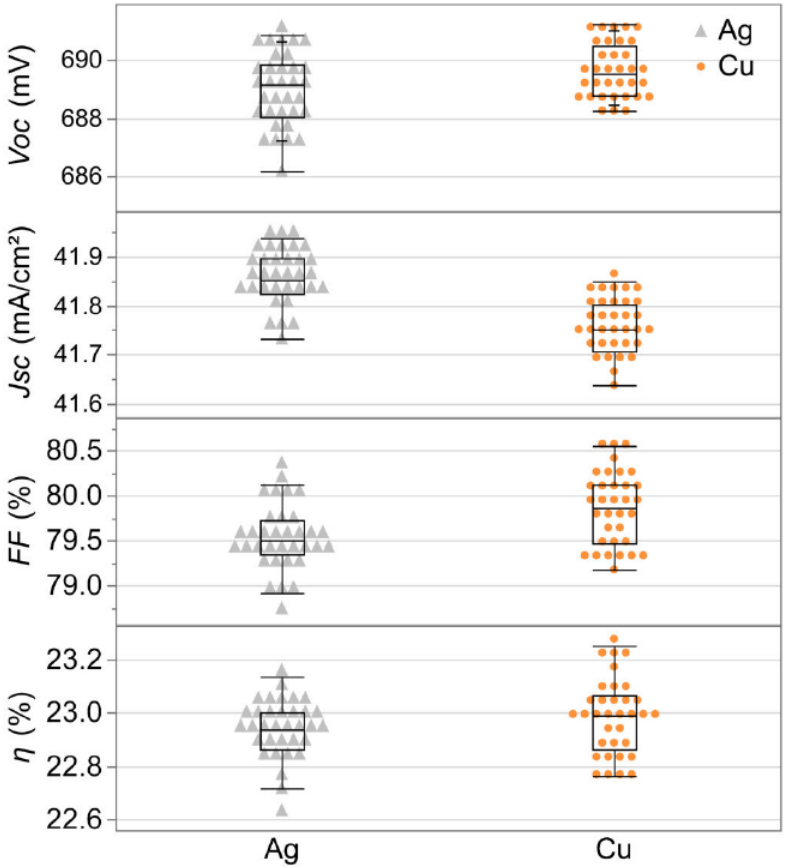
[4] N. Chen, et al., “Screen printed copper paste for metallization of IBC solar cells”, SiliconPV, 2022



Cu-ZEBRA Cells: Cu-Fingers & Cu-Busbars

- Cu-ZEBRA performs similar to Ag reference:
  - Comparable V_{OC}, pFF and cell efficiency η
  - Lower J_{SC} of 0.1 mA/cm²
  - Slightly higher FF not statistically significant
- Cu-ZEBRA concept demonstrated without efficiency losses

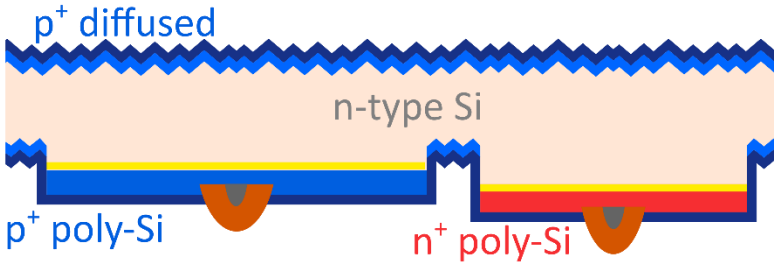


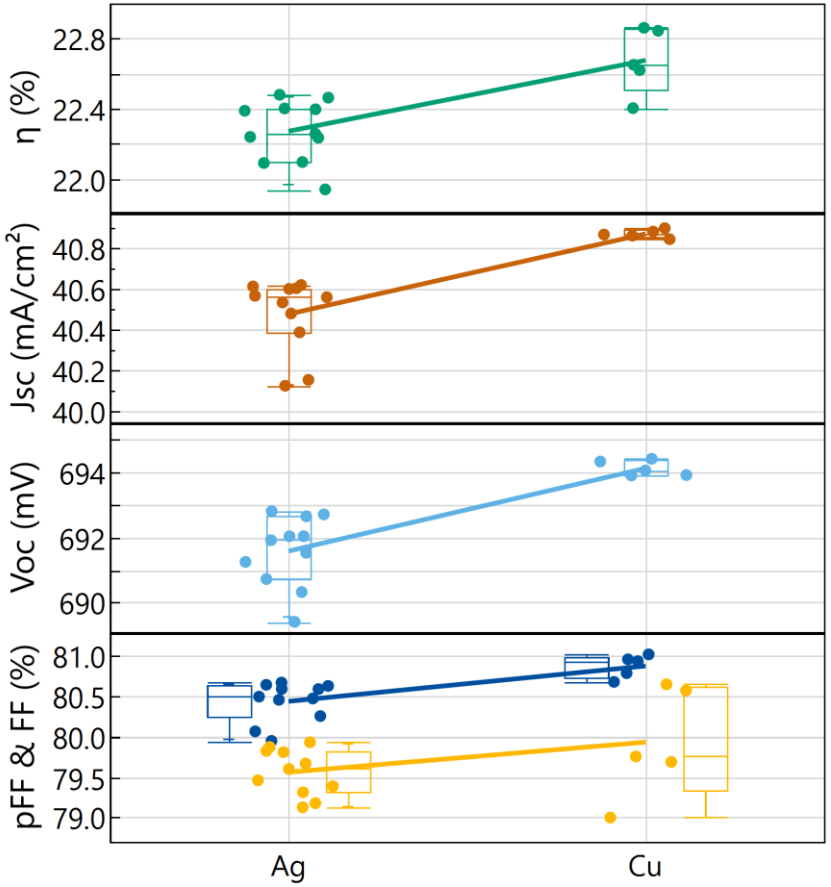


[5] N. Chen, et al., "Thermal stable high efficiency copper screen printed back contact solar cells", Solar RRL, 2022

Cu-polyZEBRA Cells: Cu-Fingers & Cu-Busbars

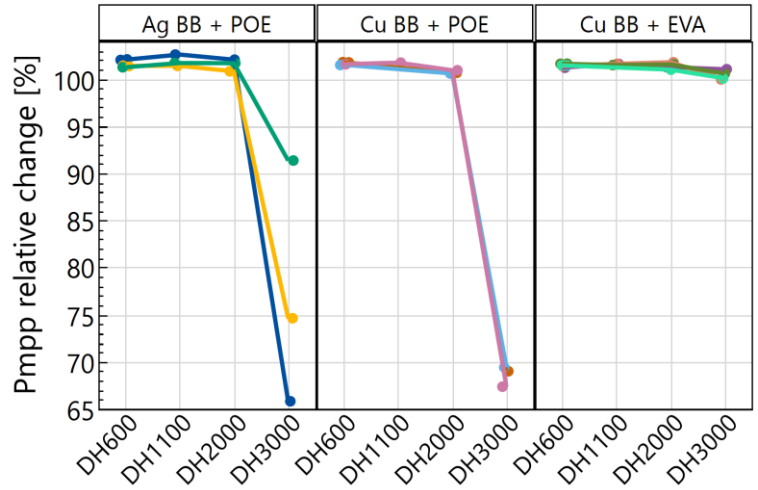
- Cu-polyZEBRA performs better than Ag reference:
  - All values higher
  - pFF-FF similar (mean values)
- But: Overall efficiency low, usually >23.5%
  → Superposition of process issue in this run
- Only 5 Cu cells so far
- Nevertheless, Cu-polyZEBRA proof-of-principle

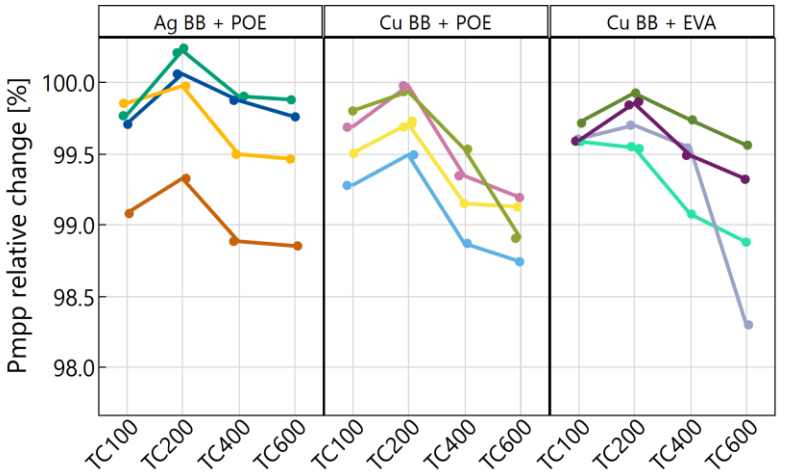




ZEBRA Module Reliability: Ag-Fingers & Cu-Busbars

- Mini-modules:
  - 2 half-cells, interconnected by automatic soldering
  - Glass – POE/EVA - backsheet
- Passes DH2000 with POE, same as Ag reference
- Passes also DH3000 with EVA
- All groups pass TC600
- Stable interconnection of Cu busbars by soldering
- V_{OC} and pFF are not degrading
  → No Cu in-diffusion from busbars

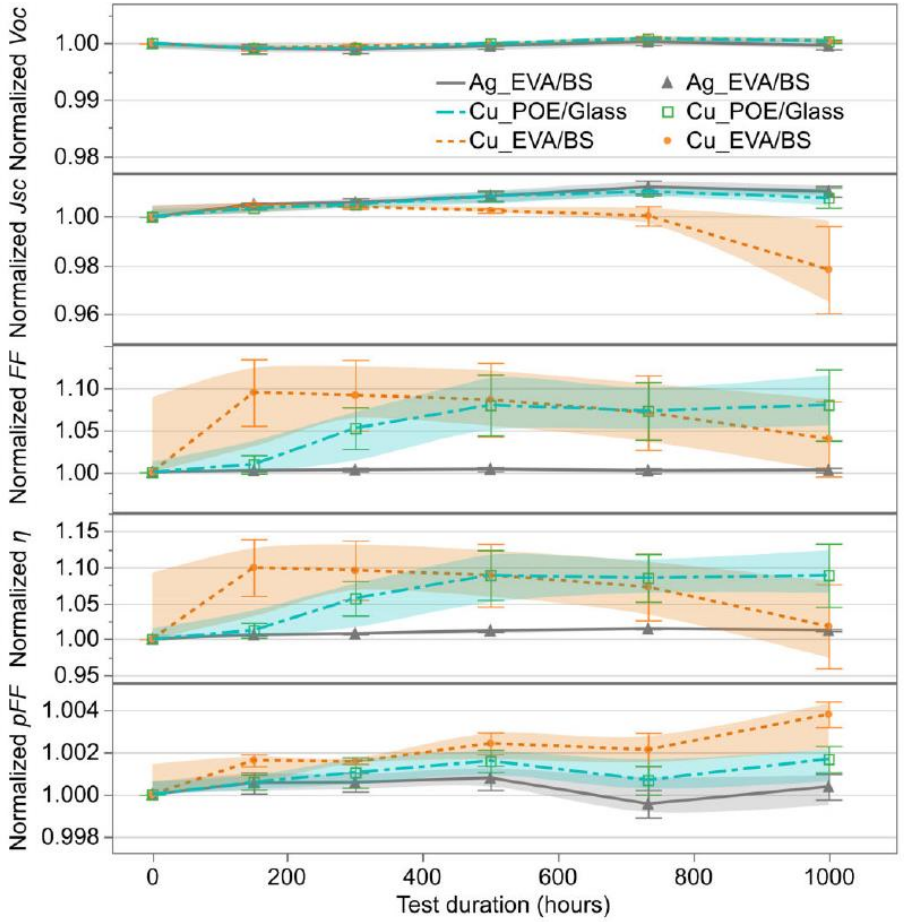




[5] D. Rudolph, et al., “Improvement of solder interconnections applied on back contact solar cells with low-temperature copper paste busbars”, SOLMAT 264, 2024

ZEBRA Module Reliability: Cu-Fingers & Cu-Busbars

- Mini-modules:
  - 2 half-cells, interconnected by ECA
  - Glass – EVA – Backsheet *or* Glass – POE - Glass
- Passes DH1000 for all variations
- V_{OC} and pFF are not degrading
  → Also no Cu in-diffusion from fingers
- Module reliability tests so far with ZEBRA modules, but similar results expected for polyZEBRA modules



[6] N. Chen, et al., "Thermal stable high efficiency copper screen printed back contact solar cells", Solar RRL, 2022

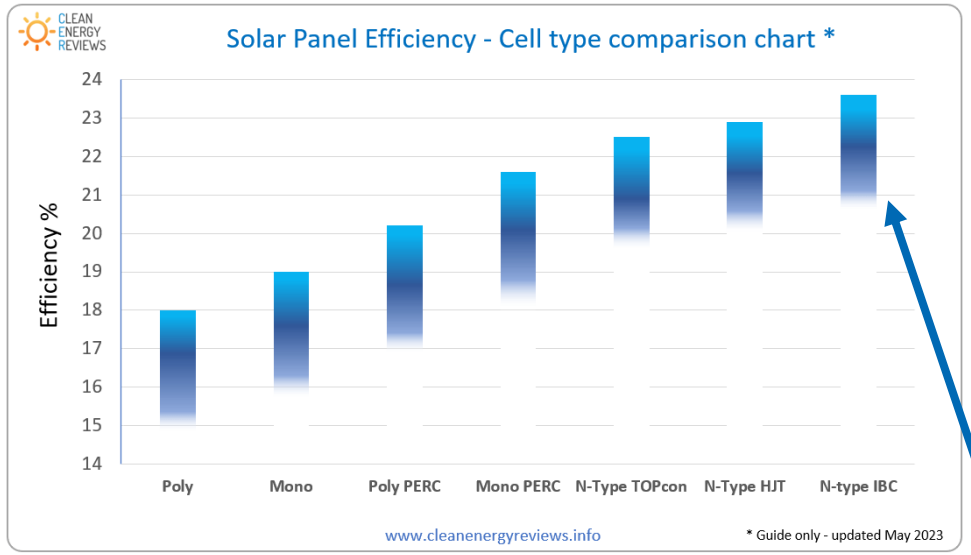
Cu-ZEBRA Full-Size Module

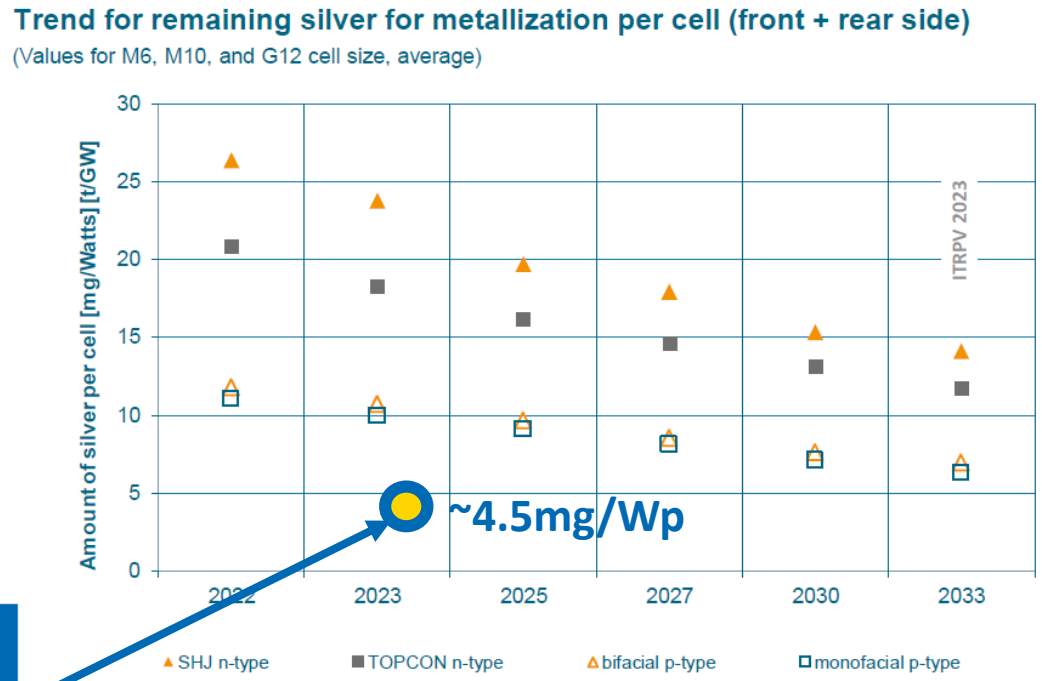
- Cu-Fingers & Cu-Busbars
- Standard soldering, glass-glass

	I_{sc} (A)	U_{oc} (V)	FF (%)	P_{mpp} (W)
Ag module	11.17	41.44	79.73	369.24
Cu module	11.11	41.54	79.31	365.94
Δ	-0.06	0.1	-0.42	-3.3
Δ_{rel}	-0.5%	0.2%	-0.5%	-0.9%

- Less than 1% power loss
- Silver usage only **~4.5 mg/Wp** (from seed layer)

Cu-ZEBRA Module Silver Consumption





- Further mg/Wp reduction expected from polyZEBRA due to higher cell efficiency

Summary

- polyZEBRA champion efficiency **24%** (Mean: 23.7%)
- Cu-(poly)ZEBRA cells similar performance as Ag references → **No contamination**
- Cu-ZEBRA modules with Ag-fingers & **Cu-BB** pass **DH3000** and **TC600**
- Cu-ZEBRA modules with **Cu-fingers** & **Cu-BB** pass **DH1000**
- Full-size Cu-ZEBRA module with **Cu-fingers** & **Cu-BB** only **~1% less power**
- **Ag consumption** for ZEBRA only **~4.5 mg/Wp**

Screen-printed Cu is a promising approach to reduce Ag consumption using established equipment

© ISC Konstanz e.V. J. Linke et al., BC Workshop 2023, Hamelin

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No.101084259

ISC research for a sunny future

Thank you for your attention

Jonathan Linke

R&D Solar Cells

jonathan.linke@isc-konstanz.de

+49 7531 36 183 - 362