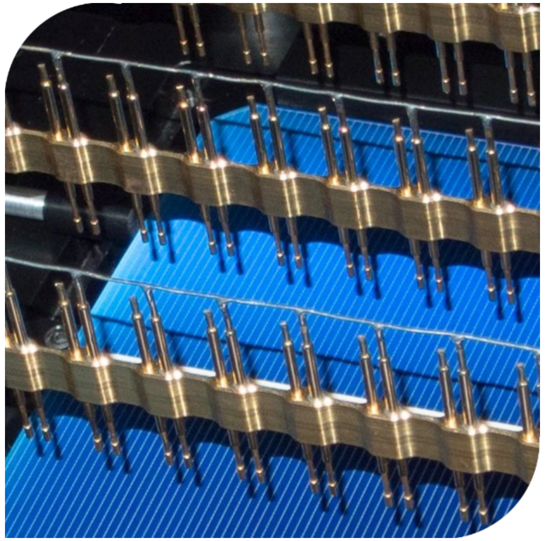
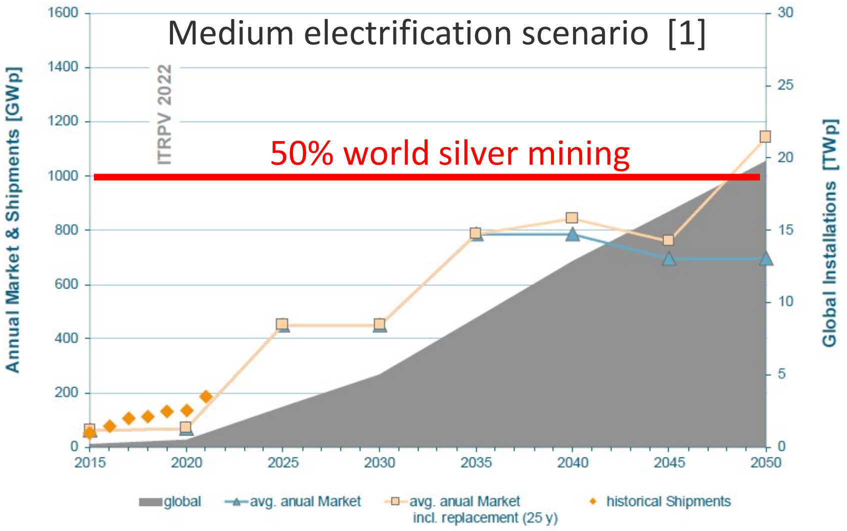


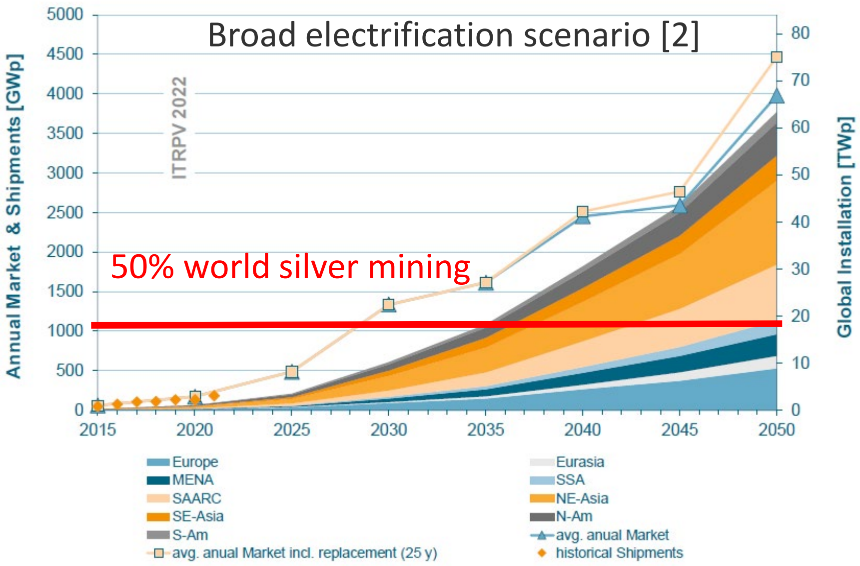
Improvement of solder interconnections applied on back contact solar cells with low-T Cu paste busbars

Dominik Rudolph

ISC research for a sunny future

Motivation: do we have enough silver?





- Current Ag consumption (PERC cell) is ~ 12-13 mg/Wp
- World silver mining: 27,800 t/a in 2019 [3] (~24,000 t/a in 2020 and 2021)
- With todays technology **50%** of world silver mining would allow for **only 1 TWp/a PV production**

[1] S. Henbest, M. Kimmel et al., „New Engergy Outlook (NEO) 2021“, Bloomberg Finance L P., July 2021
[2] D. Bogdanov et al., „Low-cost renewable electricity as the key driver of the global energy transition towards sustainability“, Energy, Volume 227, 2021, 120467
[3] World Mining Data 2021, Volume 36 C. Reichl, M. Schatz, Vienna, 2021

-> Alternative metallization and metal quantity reduction strategies are required

Motivation: Copper as replacement material

- Copper is much cheaper and features similar conductivity

Raw material comparison:	Silver	Copper	Copper vs. Silver
Price per kg in US Dollar	818	8.9	~100x cheaper (12.04.23)
Conductivity in 10^{-8} Ωm [4]	1.59	1.68	5% less conductive
Carbon footprint in $kgCO_2/kg$ [5]	155	3.97	40x better
Max level in drinking water (EPA) in mg/liter [6]	0.1	1.0	10x less toxic
Abundance in Earth's crust in ppm	0.08	68	~1000x more abundant

[4]. 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.
[5]. 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.
[6]. https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals. [Online]

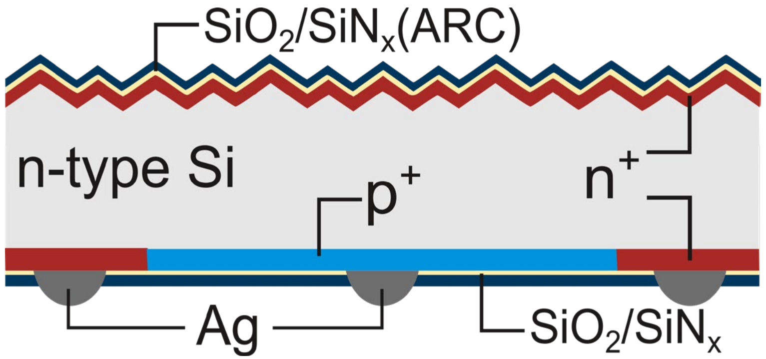
Screen printed Cu

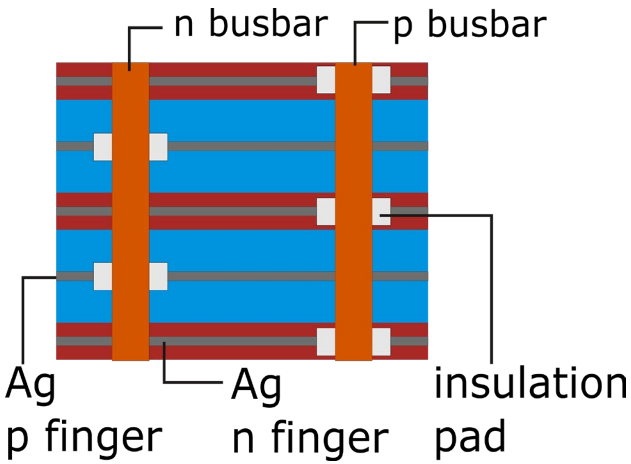
- IBC ideal for Cu screen printing
- Technology well-known from PCB
- 100% compatible with standard PV equipment
- Curing fast and at low temperature
    - Standard drying
    - “Snap curing” (300°C, few seconds with direct solid-to-solid heat transfer)

How to avoid direct contact with Si?

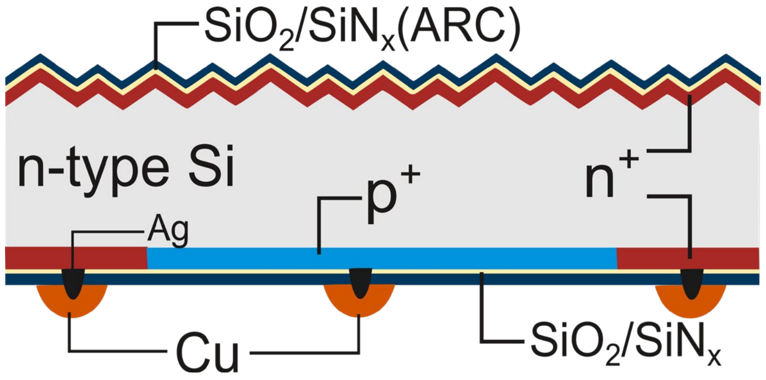
Ag replacement routes for ZEBRA IBC cells

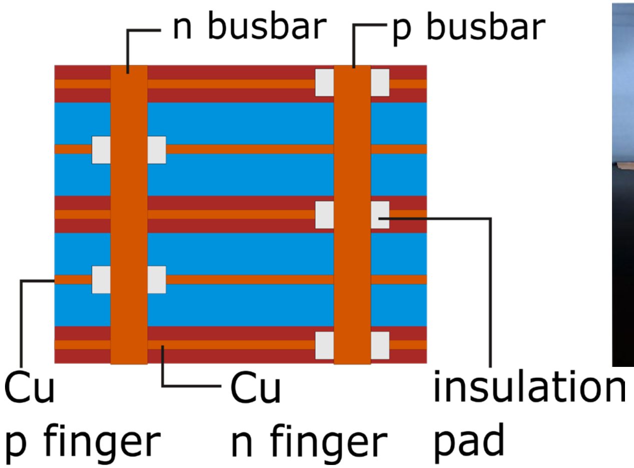
1) Replacement of **BBs** in ZEBRA

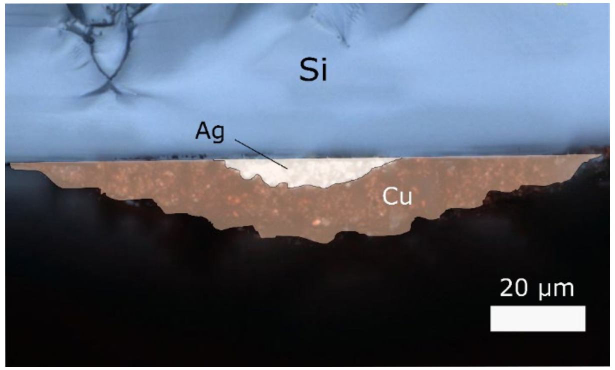




2) Replacement of **fingers** in ZEBRA







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

Route 1: soldering optimization & module results

ZEBRA with Cu BBs

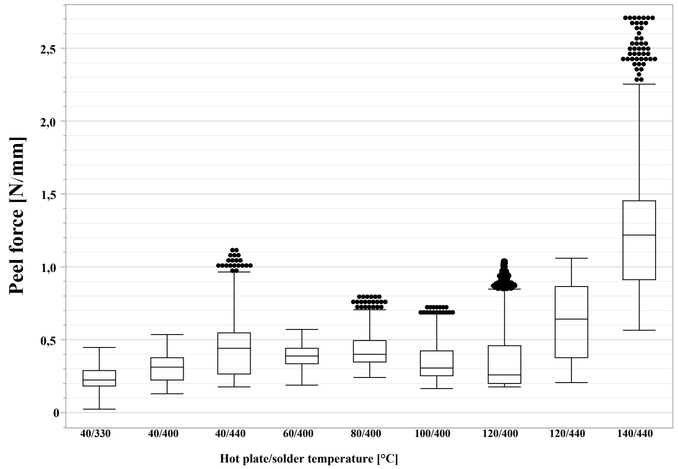
Previous results

• High throughput process capability	➢ Screen printing & short drying/curing	✓
• **No contamination** of the cell	➢ pFF & Climate chamber tests	✓
• Series resistance	➢ Line resistance & FF	✓
• Long time durability and reliability	➢ Climate chamber tests	✓
• Solderability	➢ Stringer	✓
• Adhesion	➢ Peel force	✗

[8] D. Rudolph et al., "Screen printable, non-fire-through copper paste applied as busbar metallization for back contact solar cells ", 10th Metallization and Interconnection Workshop for Crystalline Solar Cells, 2022

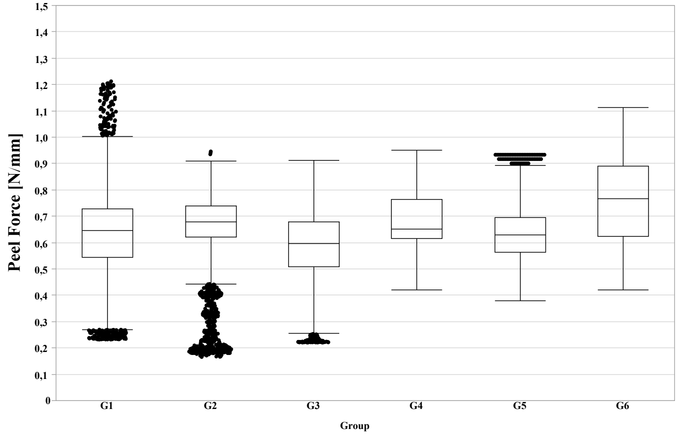
Soldering optimization

- Initial optimization by manual soldering
  - A combination of higher soldering temperature and hot plate temperature improves the adhesion



- Further optimization using automatic stringing
  - Best recipe 6 results in peel force values between 0.6 and 0.9 N/mm

→ Stable interconnection of Cu busbars by soldering, obtained using stringer with adjusted settings.



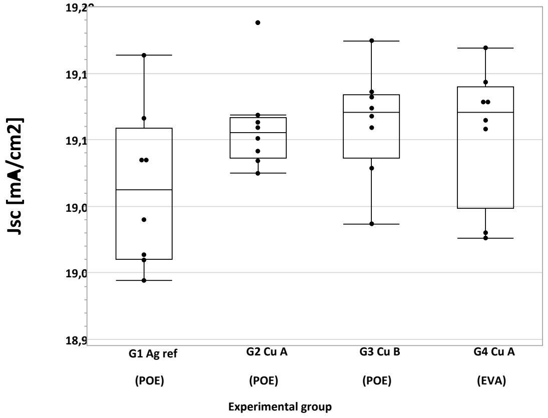
Module fabrication: Comparing encapsulation methods

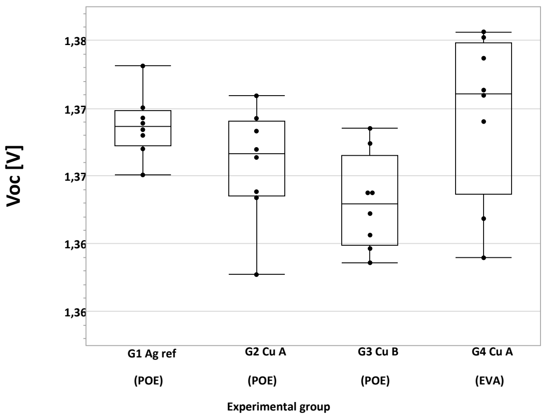
Group	1	2	3	4
Cell type	ZEBRA M6 with 6 busbars			
Busbar paste	**Reference Ag**	**Cu A**	**Cu B**	**Cu A**
Soldering process	Automatic soldering at Teamtechnik stringer using recipe 6 Ribbon: SnPb 60/40 1 x 0.24 mm^2 Cross connectors: SnPb 60/40 6 mm x 0.3 mm			
Module BOM	Glass - **POE** – transparent backsheet	Glass - **POE** – transparent backsheet	Glass - **POE** – transparent backsheet	Glass - **EVA** – transparent backsheet

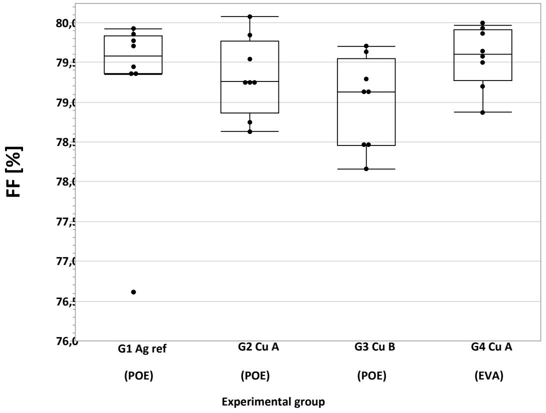
- POE: PolyOlefin Encapsulant
- EVA: Ethylene Vinyl Acetate Encapsulant

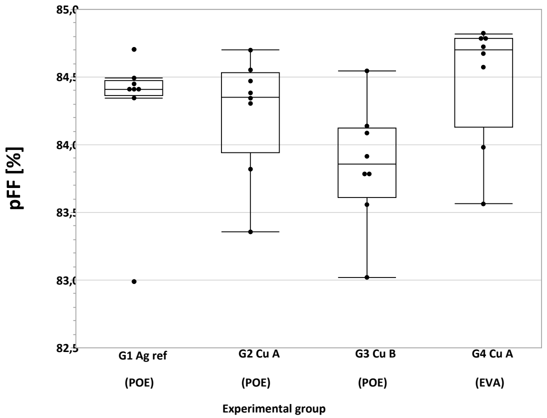
Module I–V results

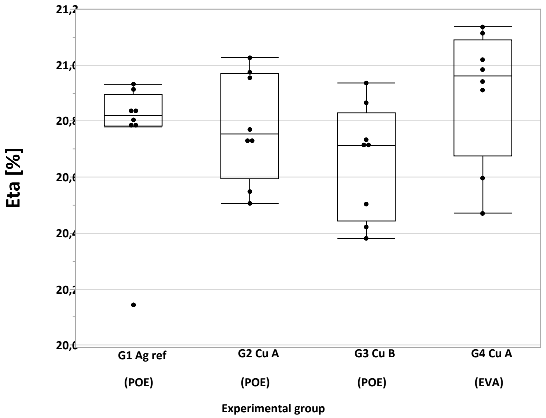
- Module results before climate chamber tests are comparable
- Slightly lower FF for group 3

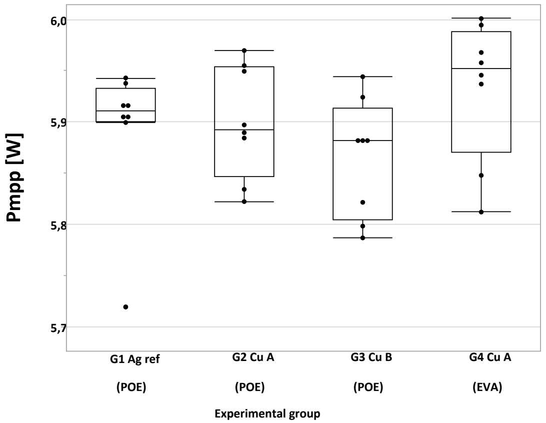








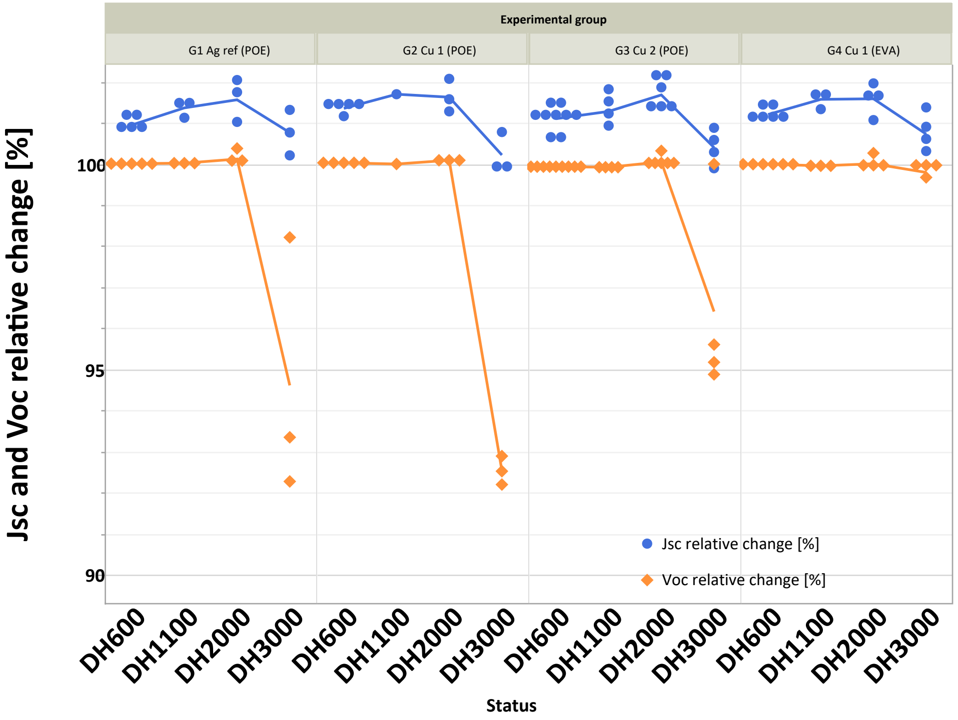




Climate chamber results Damp Heat (DH): J_{SC} and V_{OC}

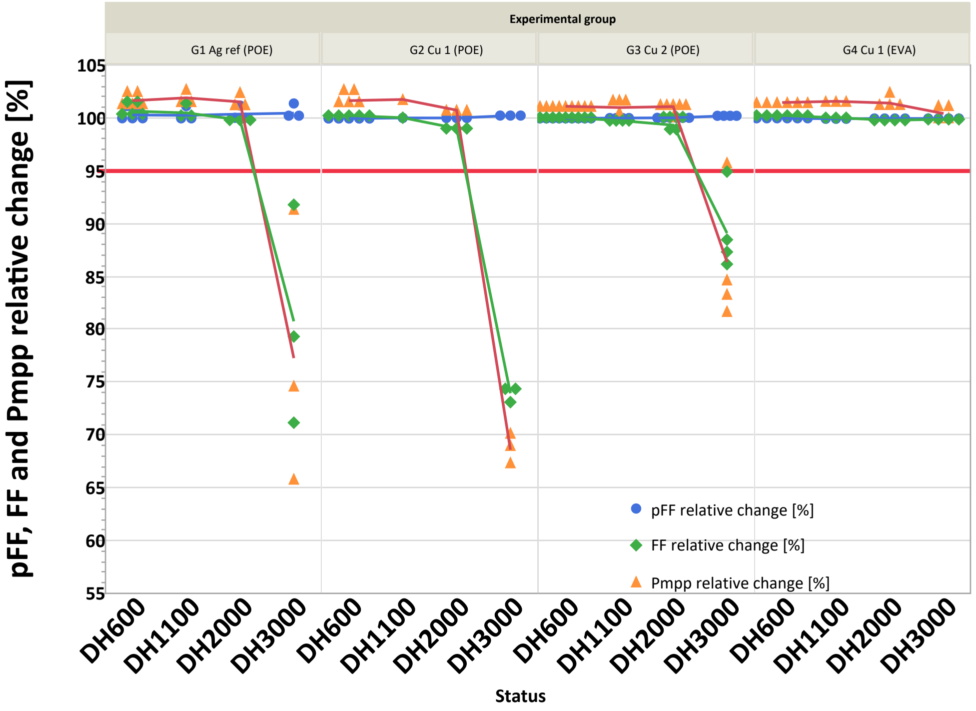
- Stable J_{SC} until DH 3000 for all groups
- V_{OC} stable until DH 2000 for all groups and until DH 3000 for group 4
- Break down in V_{OC} for groups 1, 2 and 3 during DH 3000

→ Highest stability obtained with glass-EVA-backsheet BOM

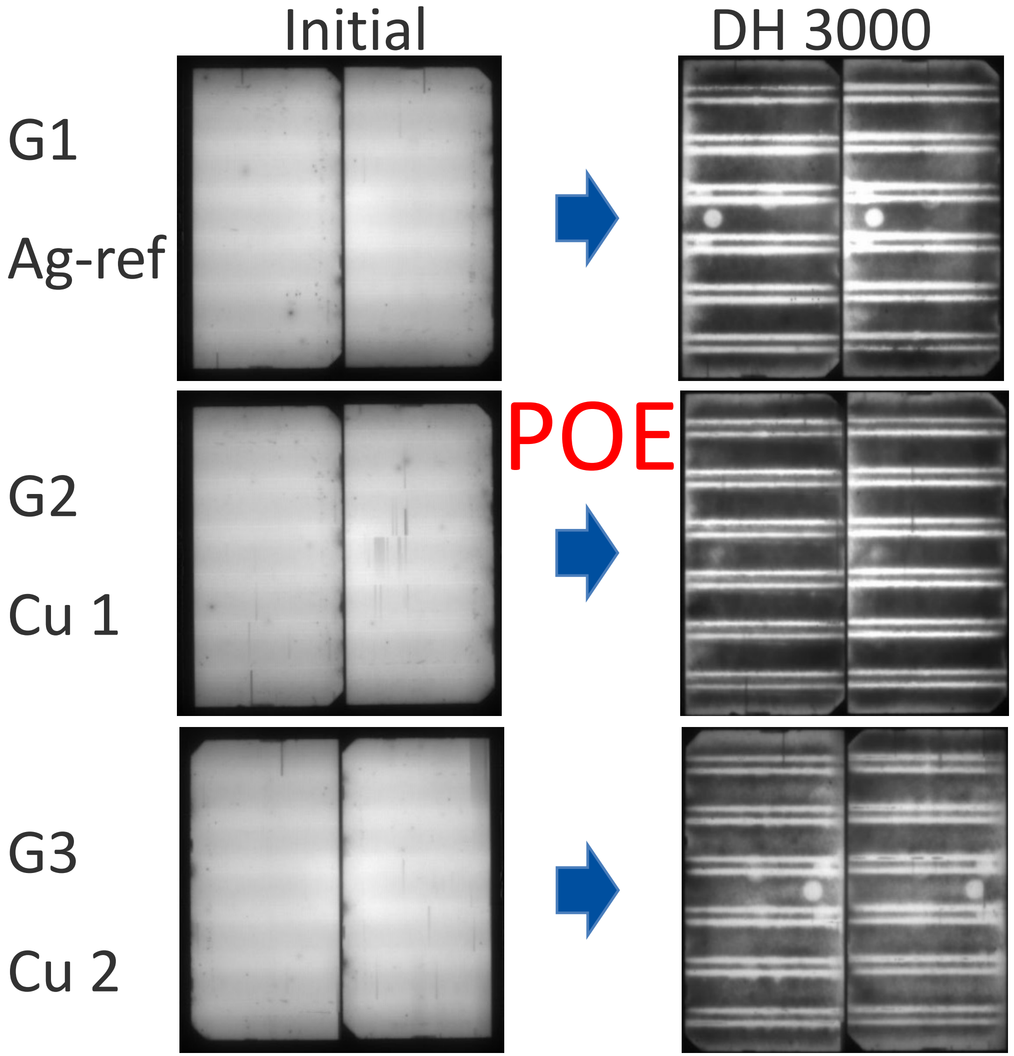


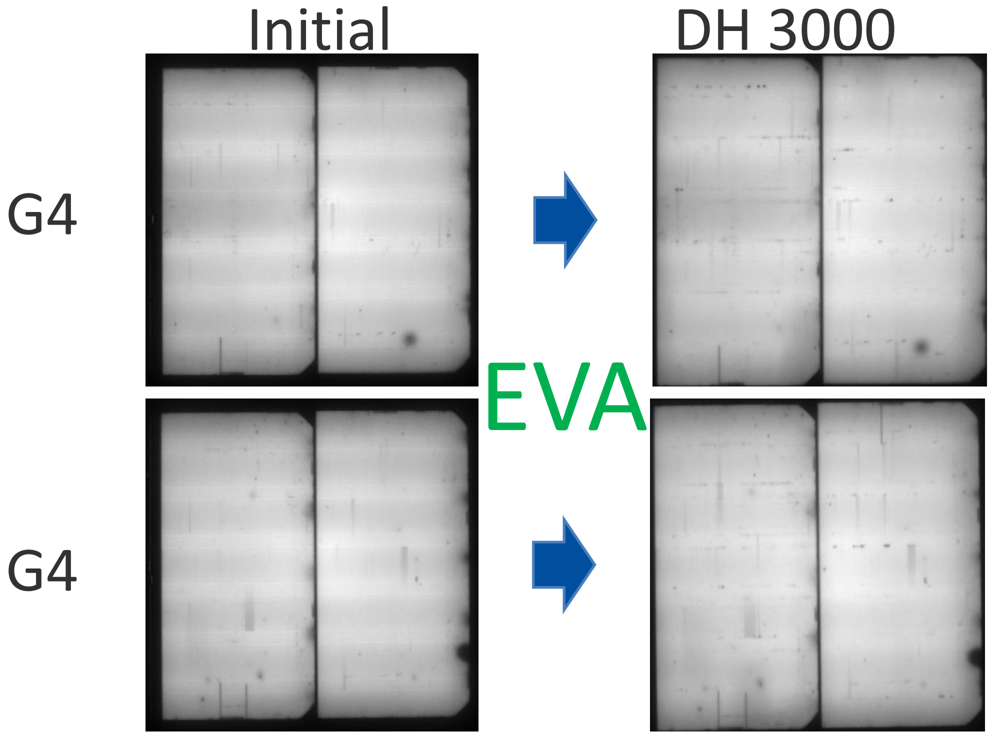
Climate chamber results DH: pFF, FF and P_{mpp}

- No degradation in **pFF** until **DH 3000**
- Break down in FF and P_{mpp} at DH 3000 for group 1 to 3
- Group 4 stable in FF and P_{mpp} until DH 3000 → **3 x IEC DH for soldered Cu busbars** with EVA encapsulation and backsheet



Climate chamber results DH: EL fault detection

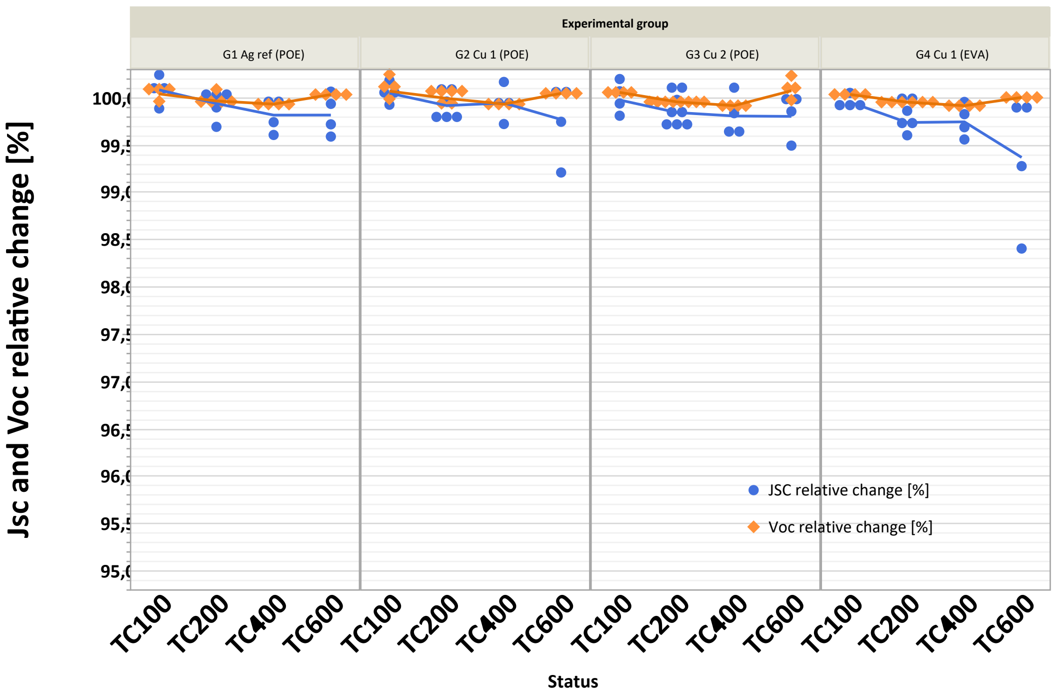


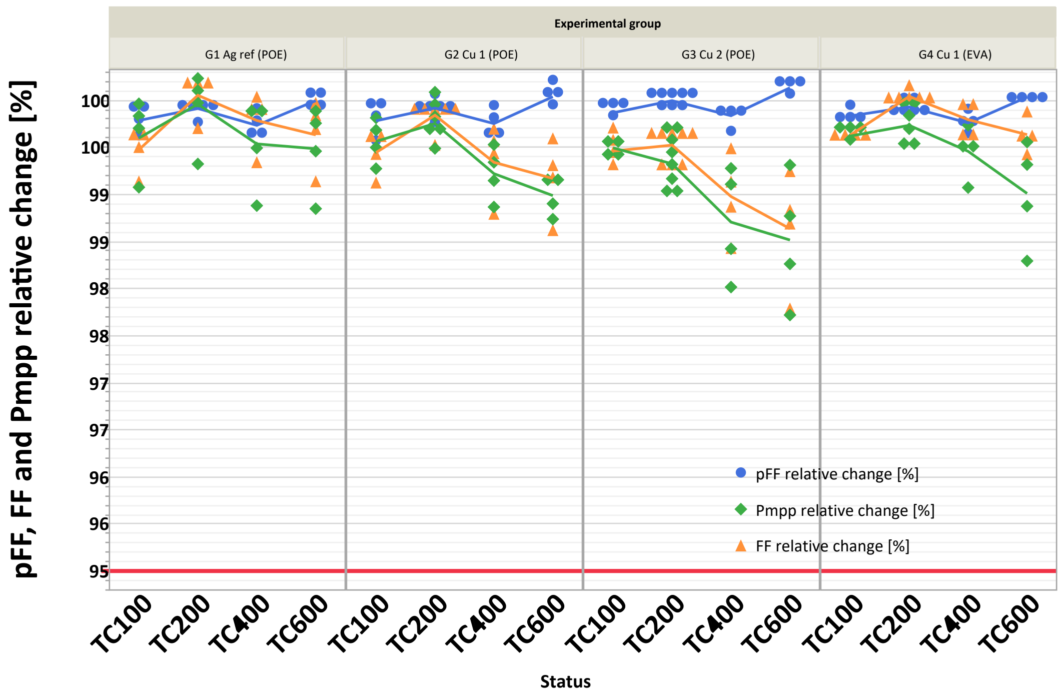


Module defect is only visible for POE encapsulated groups 1-3 after DH3000

→ Contact between BB and fingers

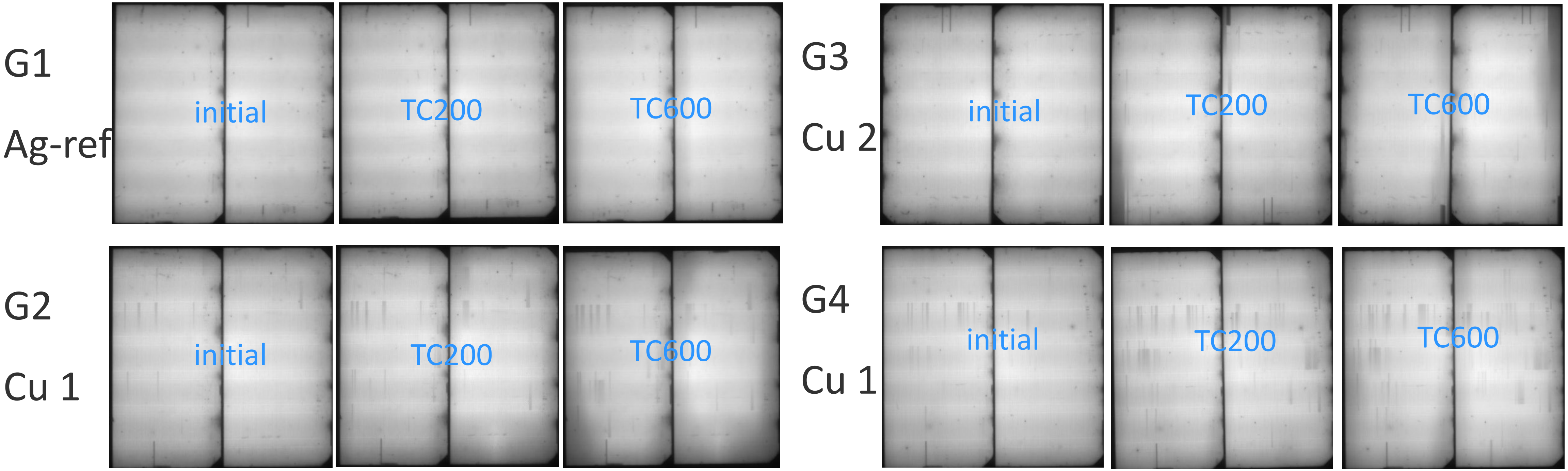
Climate chamber results: Thermal Cycling (TC)





- All modules remain stable until TC600
- No degradation of the contact → Soldering connection is no issue

Climate chamber results TC: EL fault detection



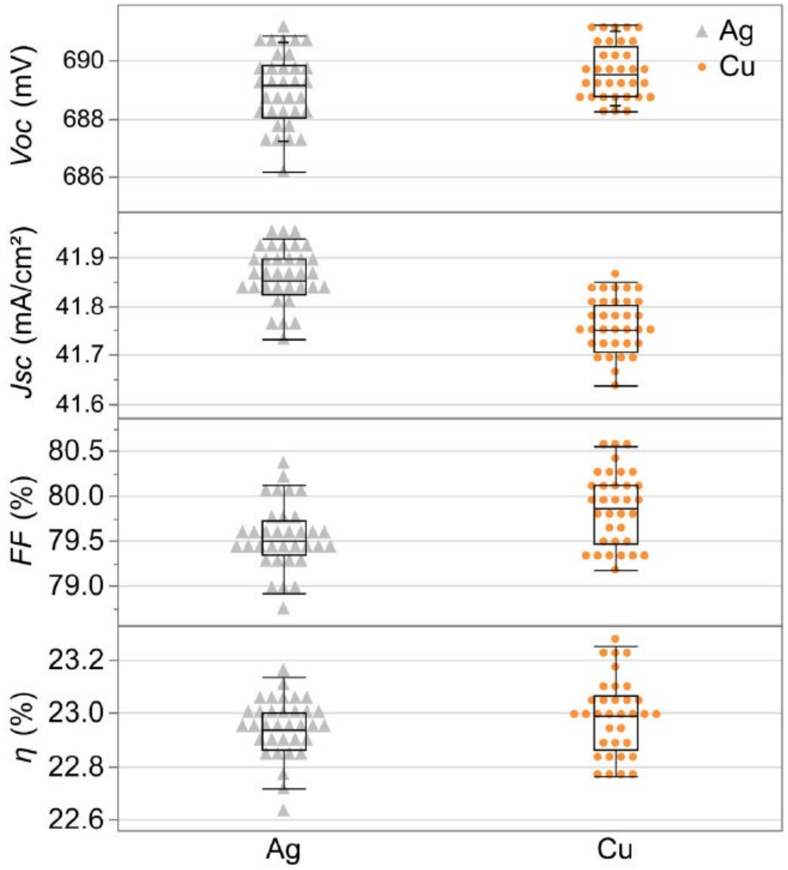
- No severe issues visible in EL images
- More finger interruptions visible for Cu paste groups
  - Thermal stress between silver finger and Cu busbar?

Outlook on route 2: Cu finger and BB metallization

For Cu cells

- Comparable V_{OC}, pFF and cell efficiency η
- Lower J_{SC} of 0.1 mA/cm^2
- Better FF of 0.3 $\%_{abs}$ but not statistically significant

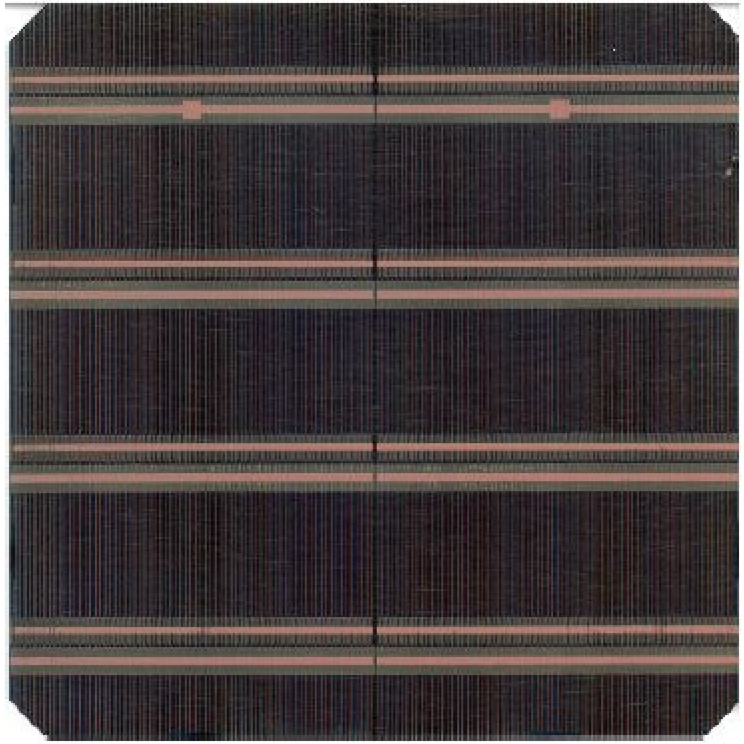
Paste	Data type	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	η (%)
Ag	Best cell	687.2	41.92	80.32	23.14
	Avg. of 34 cells	688.9±1.2	41.85±0.05	79.54±0.36	22.94 ±0.11
Cu	Best cell	690.2	41.80	80.56	23.25
	Avg. of 34 cells	689.6±0.9	41.75±0.06	79.81±0.41	22.98±0.13



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

Conclusion

- Stable interconnection of Cu busbars by soldering
- Cu BB modules with EVA+backsheet passed **3 x IEC** DH and TC
- Comparable result for Ag BB modules and Cu BB modules encapsulated in POE + backsheet: pass 2 X IEC DH)
- V_{OC} and pFF are not degrading for the Cu BB modules → Cu indiffusion is no issue



All requirements fulfilled

• High throughput process capability	➢ Screen printing & short drying/curing ✓
• **No contamination** of the cell	➢ pFF & Climate chamber tests ✓
• Series resistance	➢ Line resistance & FF ✓
• Long time durability and reliability	➢ Climate chamber tests ✓
• Solderability	➢ Stringer ✓
• Adhesion	➢ Peel force ✓

ISC research for a sunny future

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This work is supported by the German Federal Ministry for Economic Affairs and Energy (BMWi) as part of the FlexFab 2 project with funding reference numbers **03EE1081B**.

Copprint

Bundesministerium für Wirtschaft und Energie

Thank you for your attention