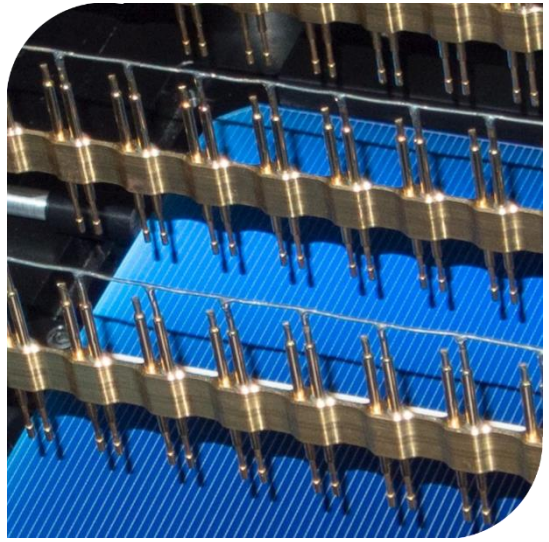



Screen printable, non-fire-through copper paste applied as busbar metallization for back contact solar cells

Dominik Rudolph[1], Rüdiger Farneda[1], Tudor Timofte[1], Andreas Halm[1], Joris Libal[1], Ning Chen[1], Florian Buchholz[1], Isaac Rosen[2], Michael Grouchko[2], Ofer Shochet[2]

ISC research for a sunny future

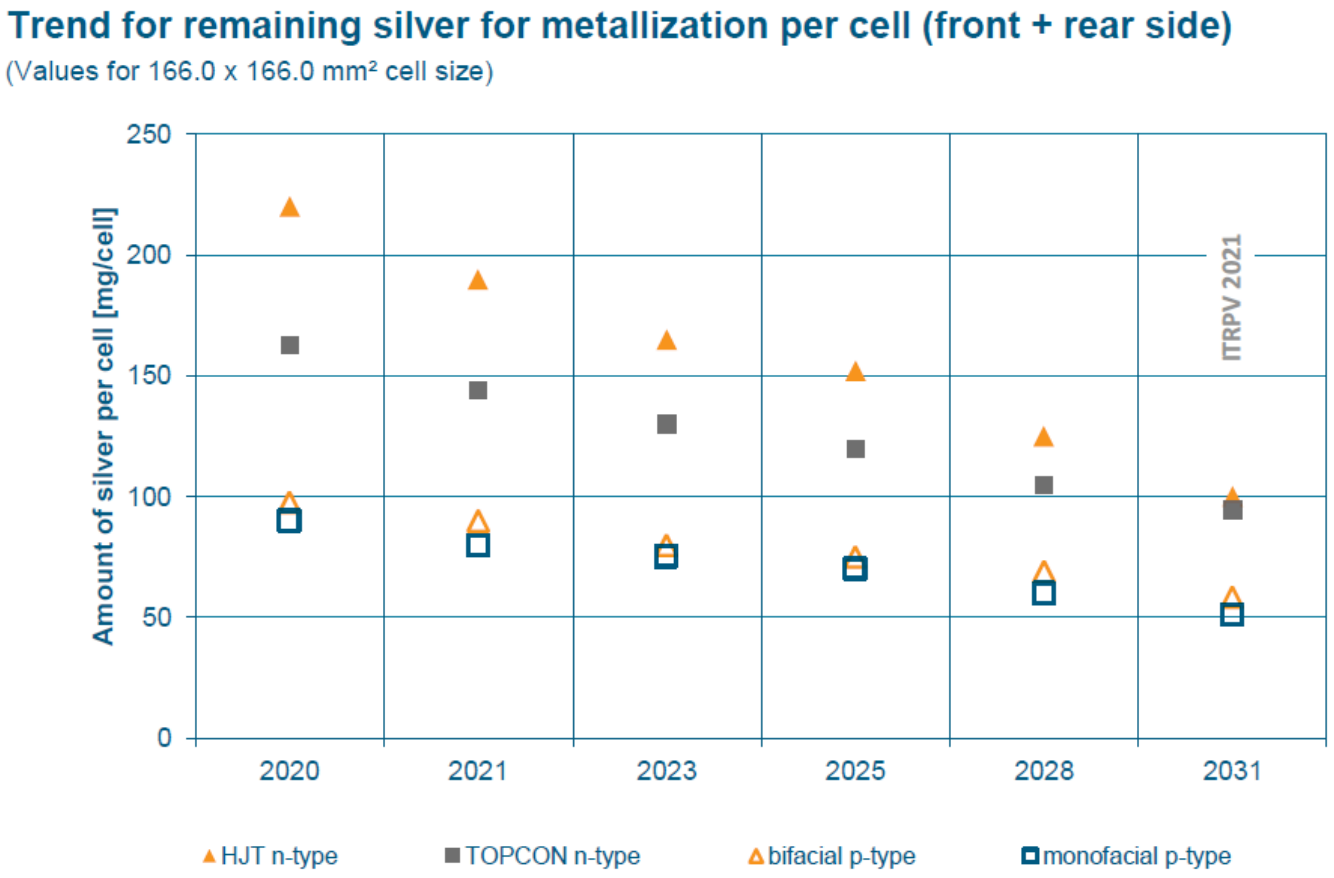
Copprint

1:International Solar Energy Research Center (ISC) Konstanz, Germany

2: Copprint, 19 Hartom st. Jerusalem 9777518, Israel

Motivation: ITRPV roadmap

- Silver is the most-expensive non-silicon material used in current c-Si technologies
- Either paste consumption has to be reduced or Ag has to be substituted by another material



- From International Technology Roadmap for Photovoltaic (ITRPV) 2020, 12th Edition, April 2021

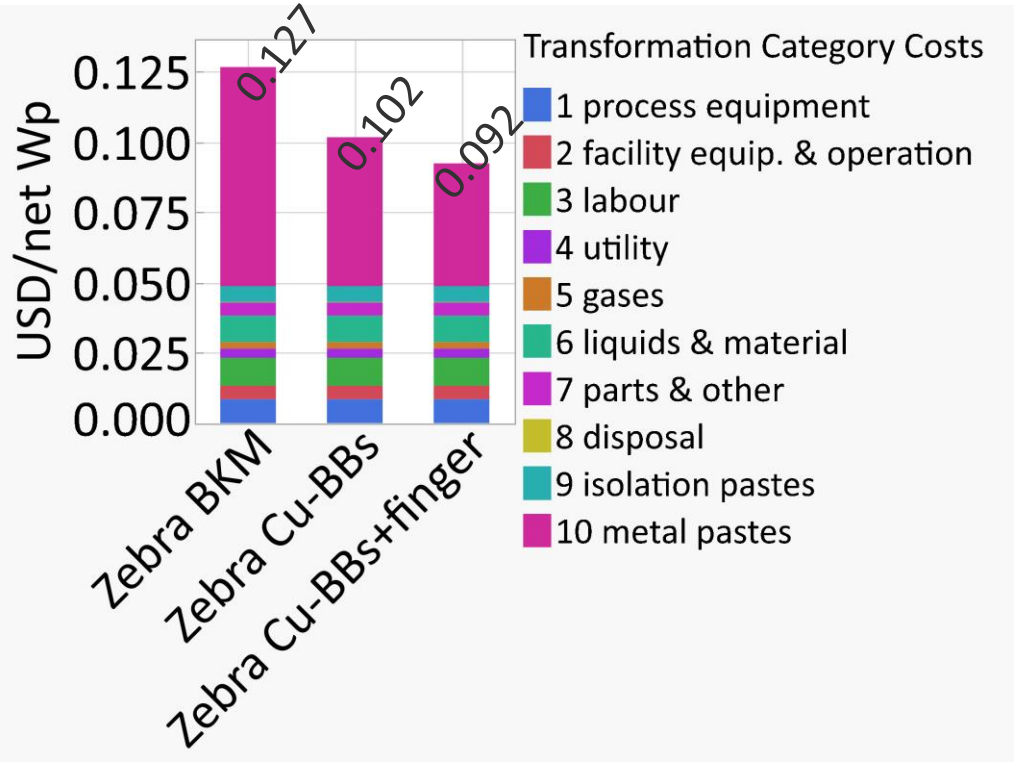
Motivation: why copper?

- Silver price is extremely volatile:
  $783 /kg (10.11.2021)
  2020 ~ $580 /kg
- Copper is a great alternative

Raw material comparison:	Silver	Copper	Copper vs Silver
Price per kg	$783	$8	~100x cheaper
Conductivity	1.59×10^{-8} Ωm	1.68×10^{-8} Ωm	5% less conductive
Carbon footprint	155 $kgCO_2/kg$	3.97 $kgCO_2/kg$	40x better
Max level in drinking water (EPA)	0.1 mg/liter	1.3 mg/liter	10x less toxic
Abundance in Earth's crust	0.08 ppm	68 ppm	~1000x more abundant

Motivation: n-type IBC Zebra metallization

- In 3d-IBC Zebra metallization the amount of silver for cell production is even higher
- CoO for a cell can be reduced by 13% if only the Ag busbars are replaced by Cu
- further CoO reduction of 6% by replacing also finger metallization with Cu



- 5 GWp/year factory located in Europe
- Ag-price: 783 USD/kg
- Cu paste price: 50% of Ag-paste price
- Depreciation periods (Process equipment 5 y, Facilities: 10 y, Building: 20 y)

Main requirements for Cu based metallization

- High throughput process capability
- Solderability
- **No contamination** of the cell
- Series resistance
- Adhesion
- Long time durability and reliabilty

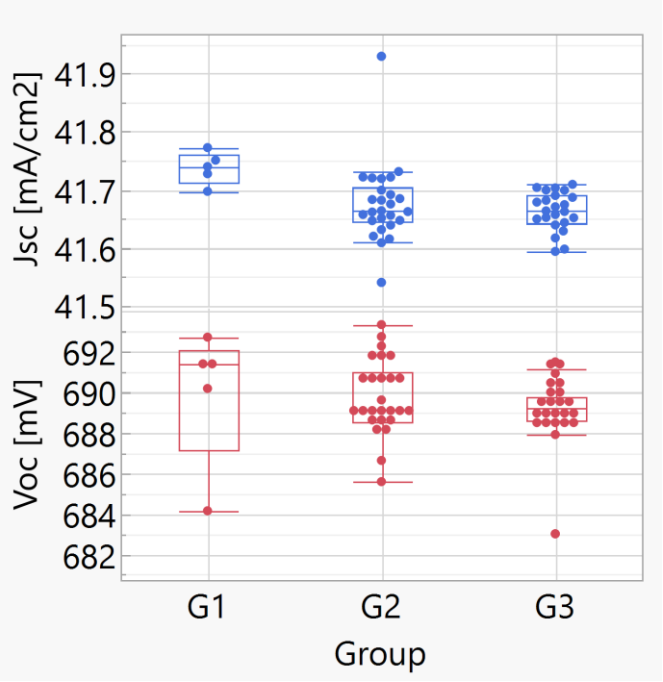
Experimental setup

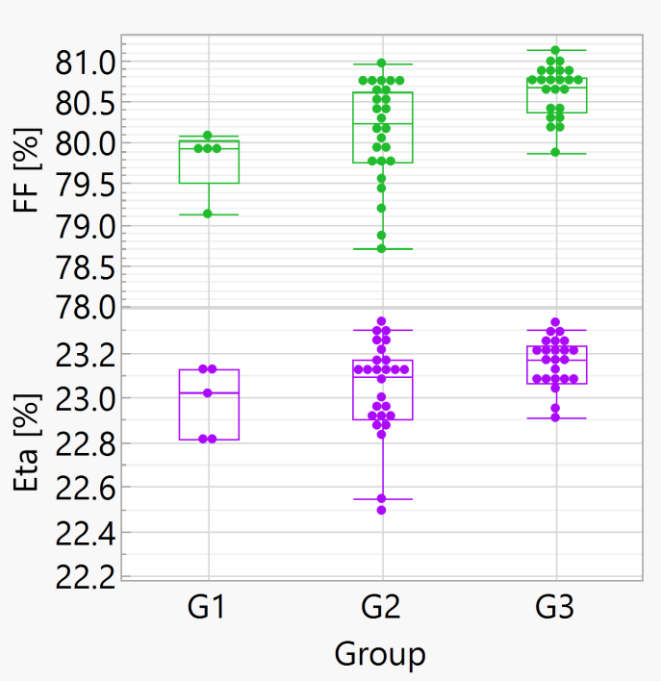
- N-type IBC cells without metallization directly taken from the production
- Metallization carried out until BB, using standard Ag and isolation paste
- Busbars print:
  - G1: low temperature Ag paste
  - G2: Cu paste LF371, laydown 76% of Ag
  - G3: Cu paste LF390, laydown 61% of Ag
  - G4: Cu paste LF370, laydown 47% of Ag
- Drying at 100°C + sintering at 300°C for 5 seconds (Cu pastes)
- IV measurement, line resistance, soldering, peel force, mini modules, climate chamber tests

Results cell IV characteristic

- Hardly any influence on J_{SC} and V_{OC}
- Increased FF due to lower series resistance of samples with Cu paste

→ slightly improved cell efficiency

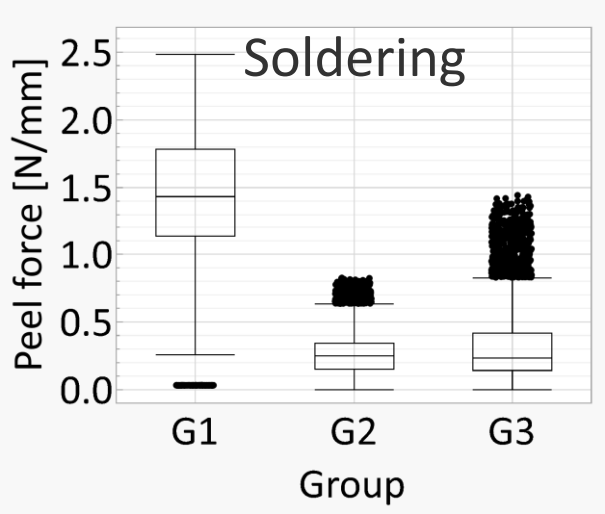


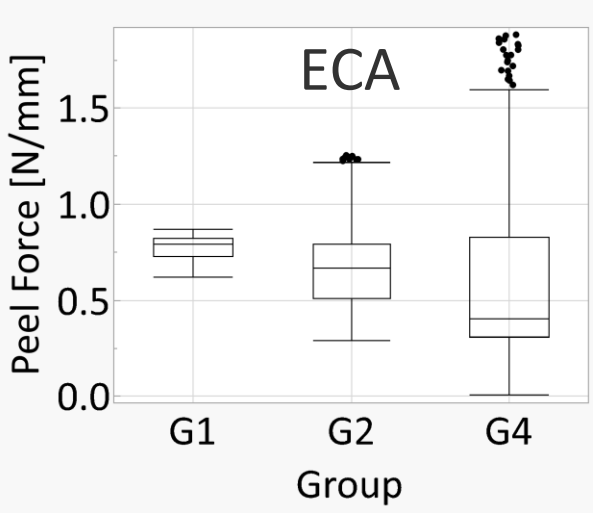


Peel force results: soldering and ECA

- Peel force of soldered ribbons on Cu BB is 0-0.8 N/mm
- Adhesion between ribbon and Cu paste is higher than between Cu paste and cell surface
- Peel force is significantly improved for G2 when using ECA →ribbons of the mini modules were glued by ECA

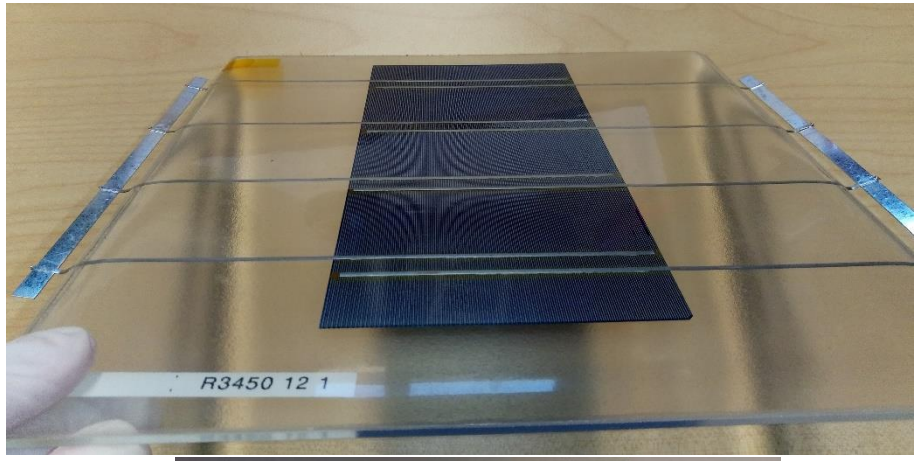
→ Adhesion of the paste on the cell surface is crucial and needs to be improved

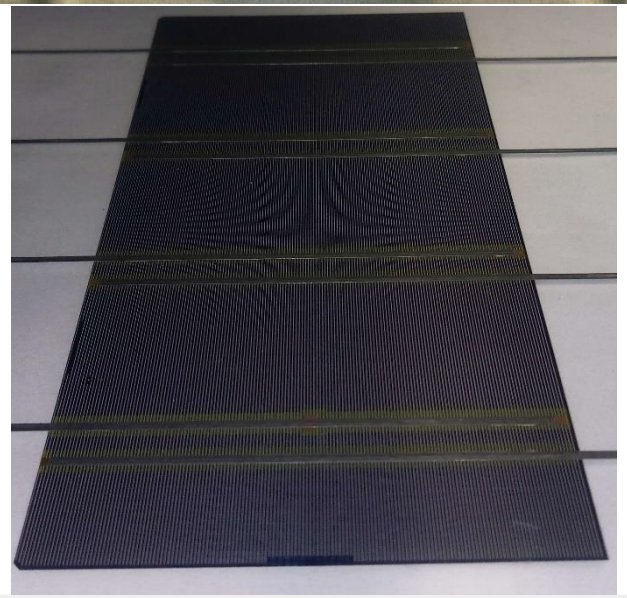




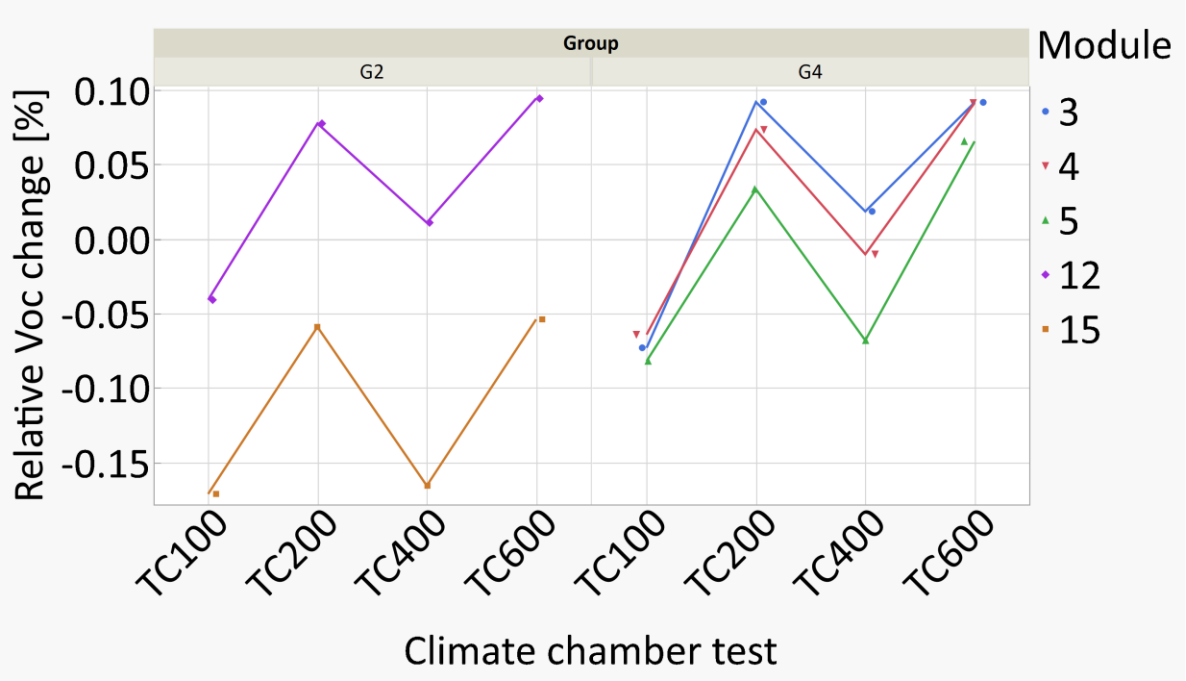
Climate chamber tests

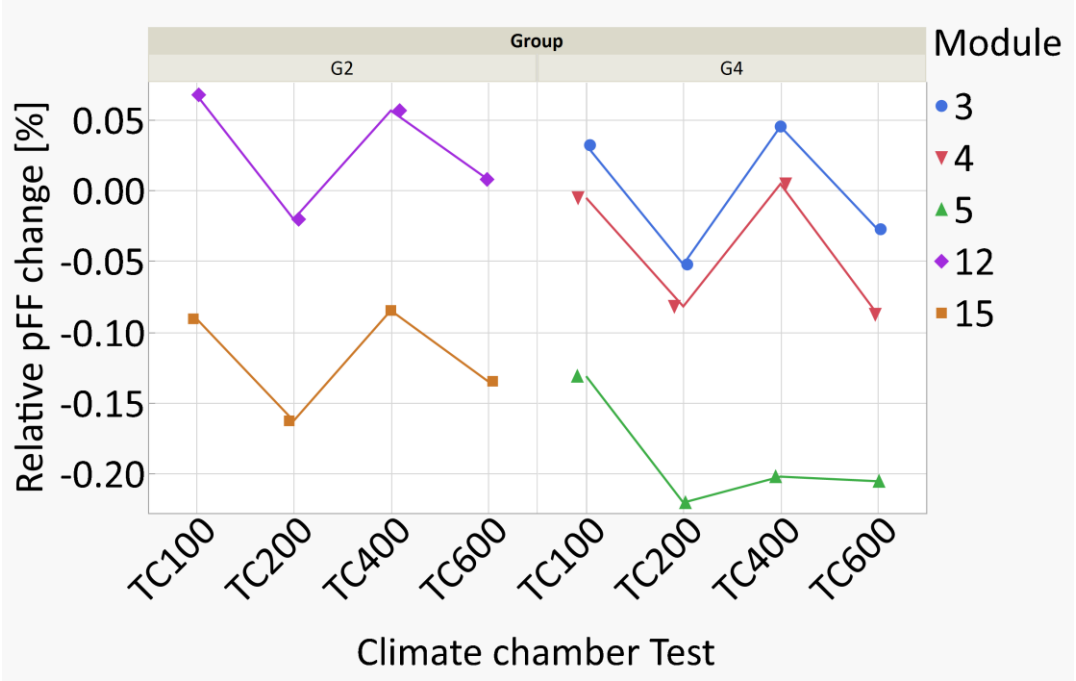
- Main motivation: rule out Cu penetration
- Half cell mini modules, ribbons connected via ECA
  - ECA was used instead of soldering to improve adhesion
- Front glass, rear back sheet with EVA as encapsulate
  - Worst case scenario as this combination is reactive and permeable
- TC up to TC600
- DH up to DH3000
- IV and EL after TC100, 200, 400 and 600 as well as DH500, 1000, 2000 and 3000





Thermal cycling results

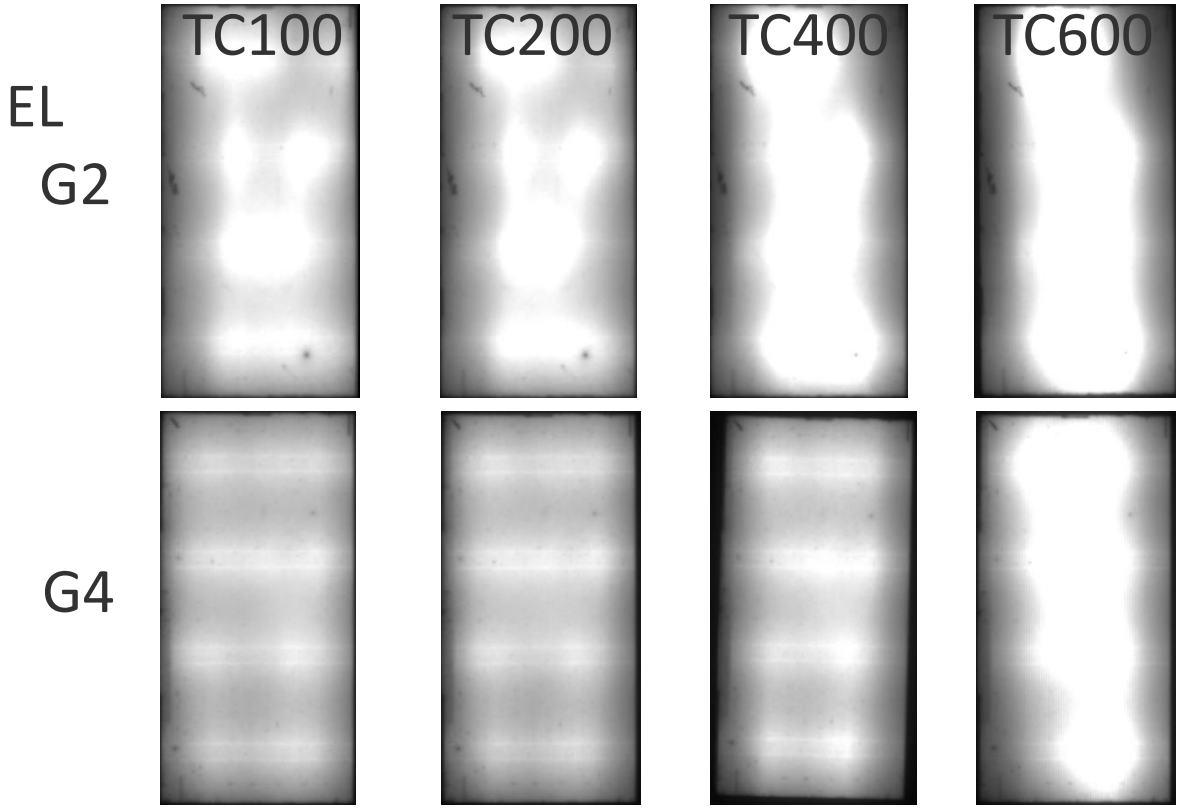


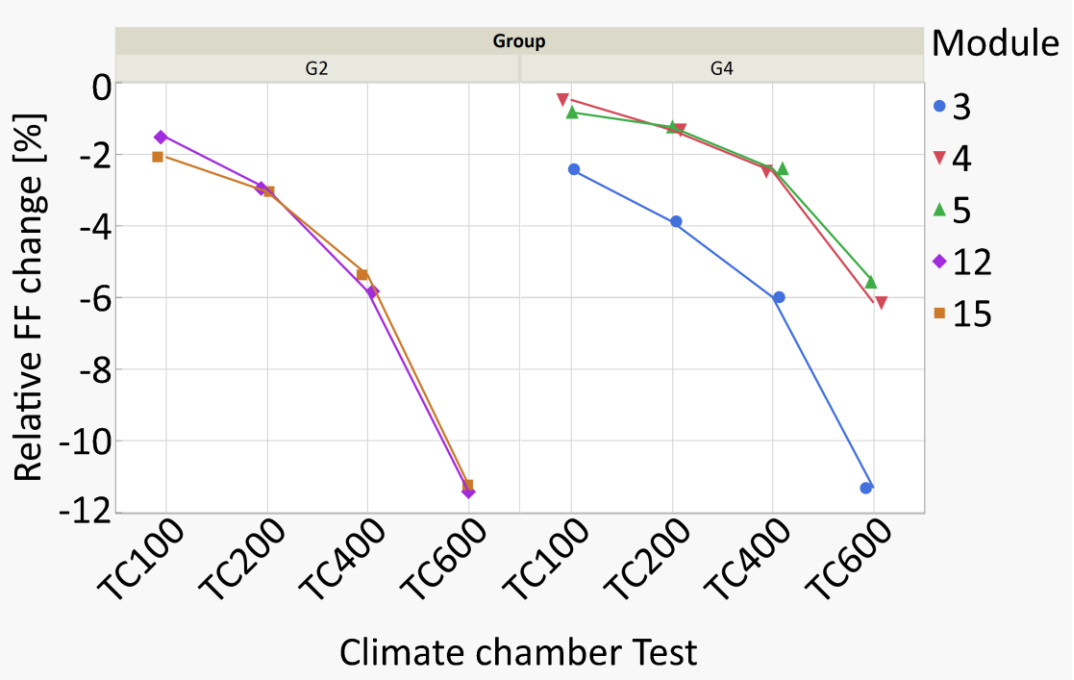


- V_{OC} and pFF do not change significantly → **no Cu indiffusion**

Thermal cycling results

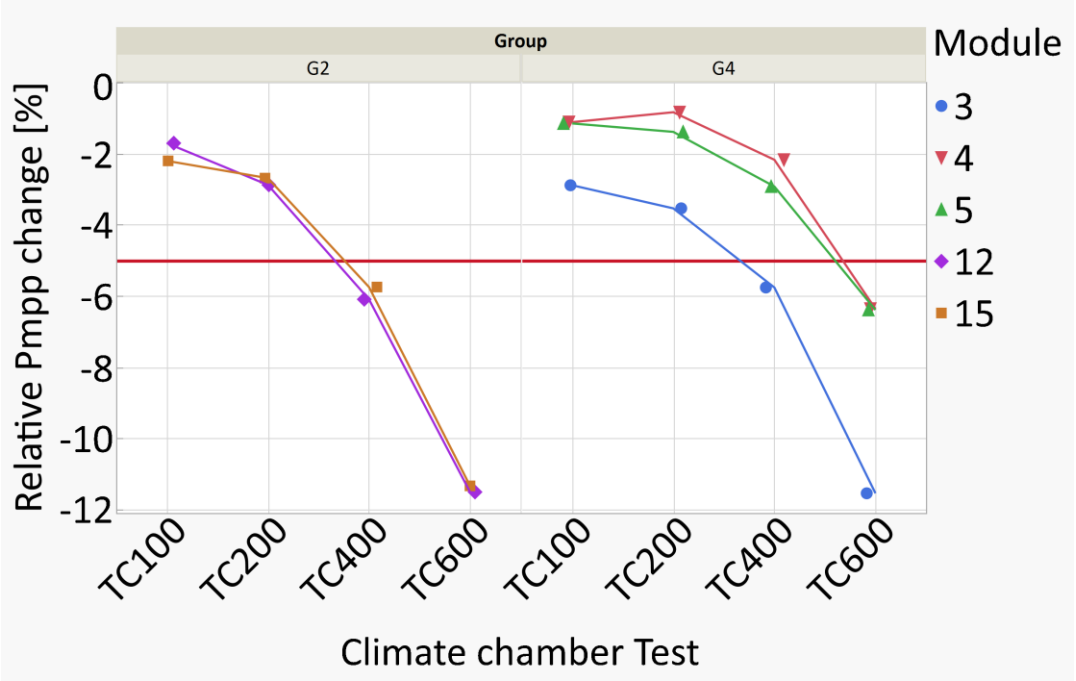
- Reason for FF drop: Contact between Cu & Ag paste or between ribbon and Cu paste



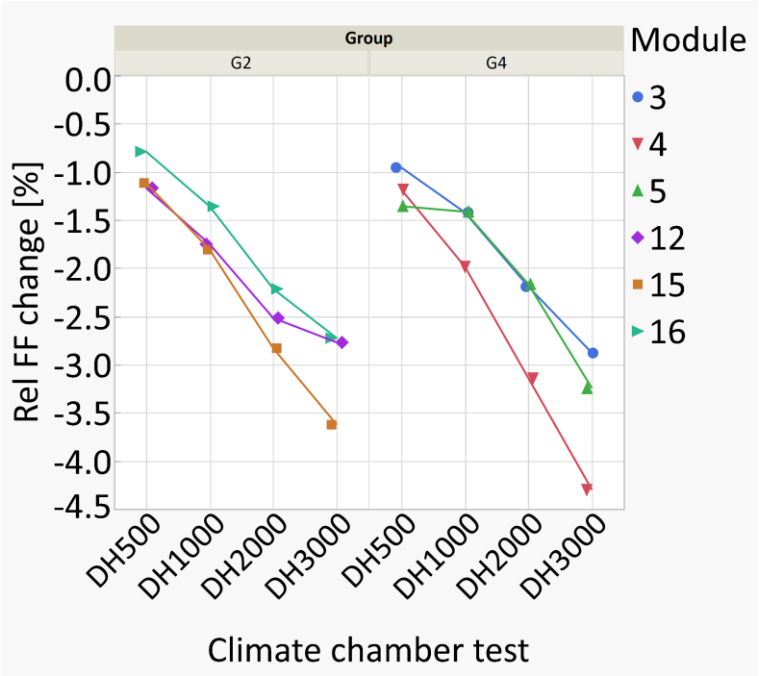


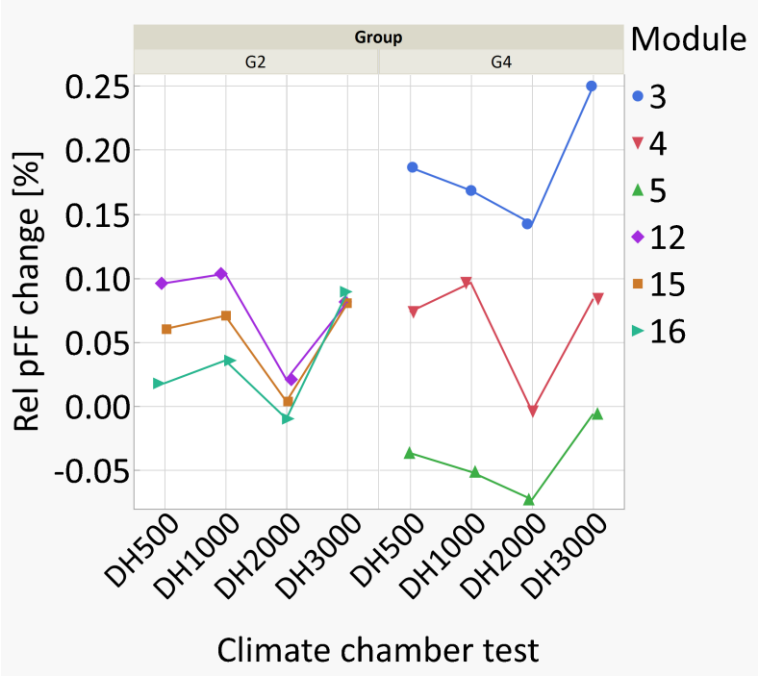
Thermal cycling results

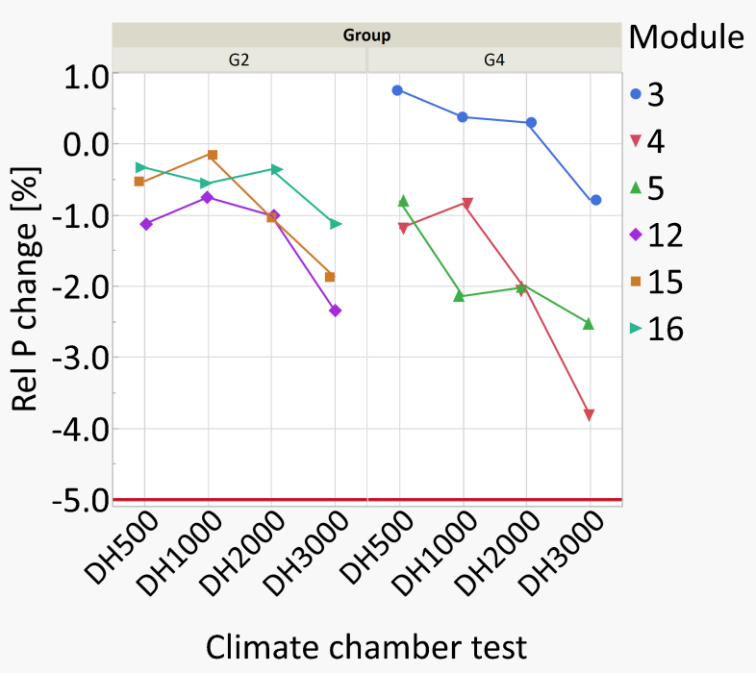
- All tested modules passed TC 200 (1xIEC)
- Two modules of G4 passed TC400



Damp heat results





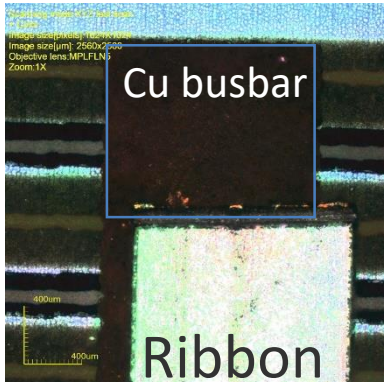


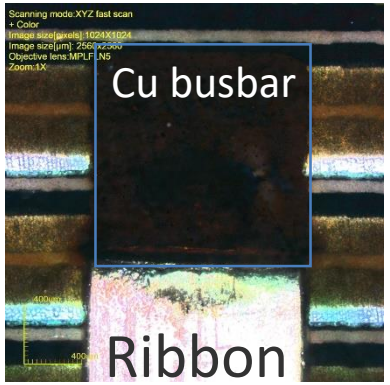
- Up to DH 3000 all modules survived the test cycles with a max power drop of 3.8 %
- Important: pFF shows no degradation → no Cu indiffusion
- FF is reduced due to the same issue observed after TC

Damp heat results

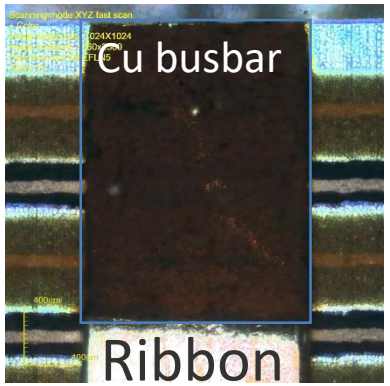
- Surface of the Cu paste is obviously oxidized → darker colour
- As the FF drop is moderate an oxidation underneath the ribbon seems unlikely

G2





G4



TC 600*

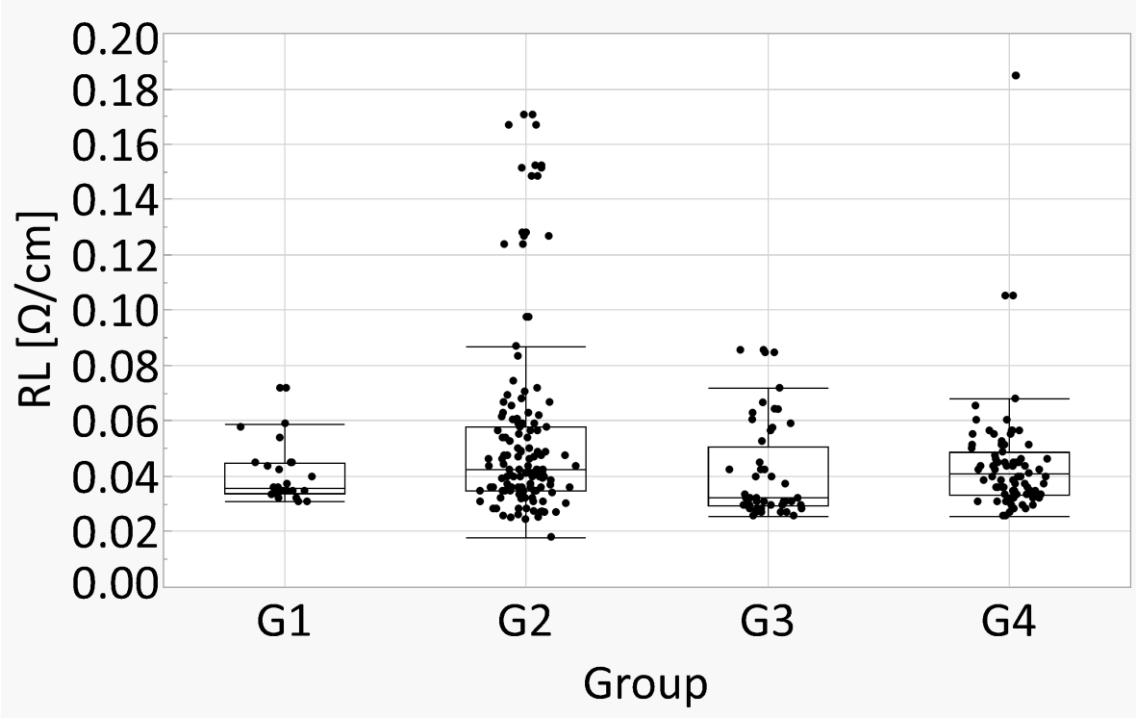
DH 3000*

*images taken through back sheet & EVA layer

Line resistance Cu busbars

- Line resistance measured by 4-point probe
- Busbar width 1.5 mm, height ≈12 µm

- All three Cu pastes are comparable to the silver reference G1
- With paste LF 390 (G3) the lowest line resistance of 0.032 Ω/cm is obtained
  → $\rho \approx 5.76\ 10^{-8}\ \Omega m$ (pure Cu:$1.68\ 10^{-8}\ \Omega m$)



Requirements fulfilled

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

Conclusion

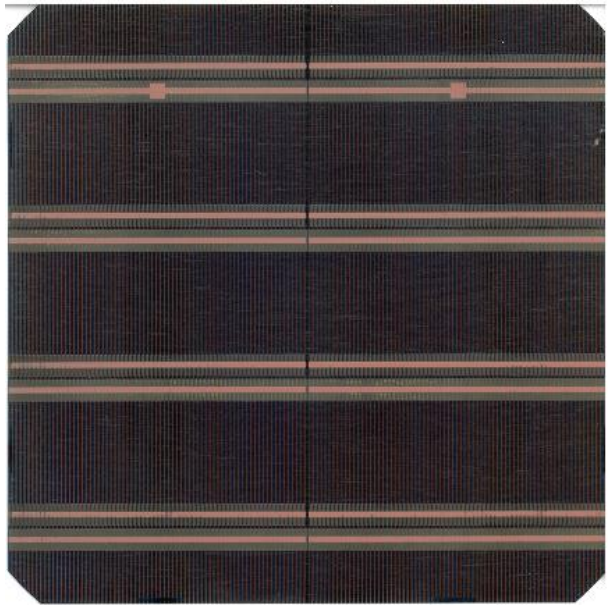
- Cu paste from Copprint Ltd. can be a valid replacement for silver busbar paste in n-type ZEBRA IBC solar cells
- IV characteristics and line conductivity are comparable to cells made with Ag BB
- Peel force tests made after soldering are low compared to Ag busbar, while ECA glued samples reached better values
- Weak adhesion between Cu paste and substrate is the main reason
- After 3 times IEC DH and TC modules show no pFF degradation

  → **Cu indiffusion is no issue**

Outlook –full Cu metallized cell

- First cells with only **25 mg silver** per cell were made
- Cu pastes and used screens are not yet optimized!
- Very promising results with high V_{OC} and pFF values

		Jsc	Voc	FF	Eta	SunsVoc	pFF
Cu finger&BB	**Best cell**	**41.24**	**0.6894**	**78.37**	**22.28**	**0.6892**	**82.63**
	Average	41.18	0.6891	77.75	22.06	0.6889	82.65
	Std. dev.	0.04	0.0004	1.04	0.31	0.0005	0.16
Reference_ Ag finger&BB	**Best cell**	**41.30**	**0.6892**	**79.99**	**22.77**	**0.6889**	**83.37**
	Average	41.27	0.6881	78.70	22.35	0.6878	82.62
	Std. dev.	0.05	0.0011	1.49	0.46	0.0011	0.44



Acknowledgements

Thank you for your attention

- 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**.

FlexFab 2

Bundesministerium für Wirtschaft und Energie