Reinforcement of Screen-printed Copper Paste by Electrodeposited Copper for Metallization of Silicon Heterojunction Solar Cells

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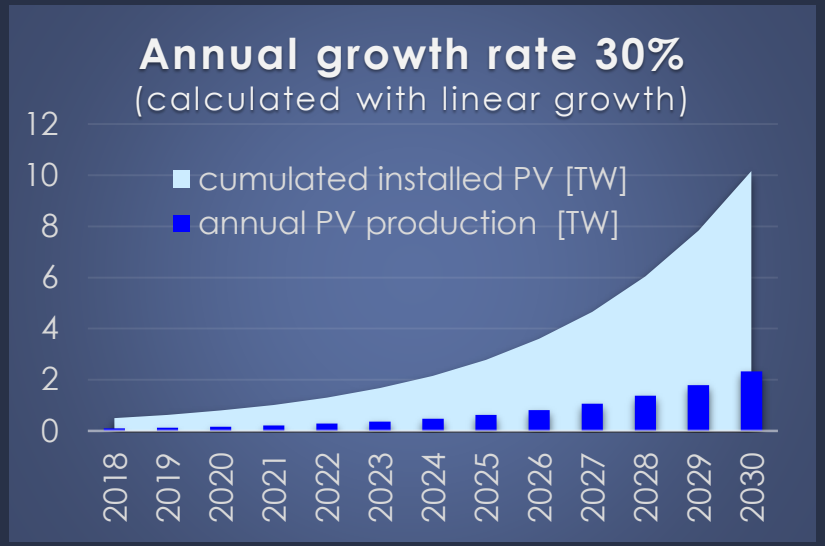
Amazingly growing PV production

- For today's PV production more than **2000 metric tons of silver** are consumed– more than 10% of the entire annual supply [3]
- Fast growth of PV production capacity is needed to reach zero-CO2-emissions in 2050.
  Terawatt scale production is postulated already for 2030 [1] [2]
- Even with strongly reduced silver consumption per cell,
  50 mg for PERC and 100 mg for n-type and bifacial cells (ITRPV projection for 2030[4]), **12 000-21 000 tons** of silver would be required for an annual production of 1.5 Terawatt
  (calculation with 50-100 mg silver and 6.3-7 W per M6-cell)



10 TW total

2 TW p.a.

- TCOs are excellent barriers against copper diffusion [4] [5] and this makes heterojunction cells the perfect structures for copper metallization

[1] N. Haegel et al., Science, 2019
[2] P. Verlinden, J. Renew. Sustain. Energy, 2020
[3] World Silver Survey 2020, silverinstitute.org
[4] C. Liu et al., "ITO as Diffusion Barrier Between Si and Cu", ECS, 2005
[5] J. Yu et al., "Tungsten doped indium oxide film: Ready for bifacial copper metallization on silicon hetrojunction solar cell", Solmat, 2016

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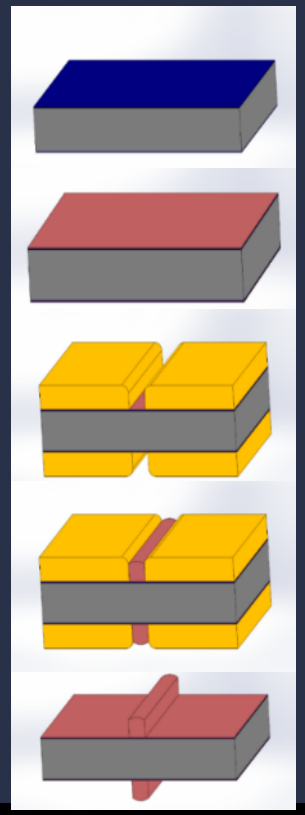
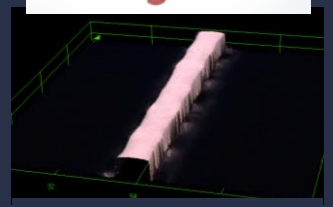
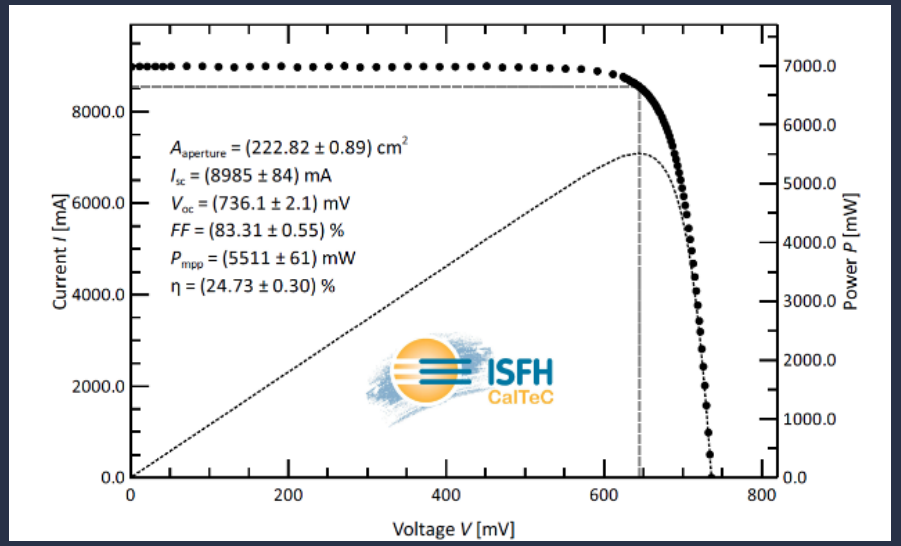
Reference process with PVD seed layer and hotmelt-inkjet patterning





Width	Height
12.6 µm	8.9 µm

- Line resistivity: 2 µΩ·cm
- Contact resistivity: < 1 mΩ·cm²
- Adhesion: peel force 4 – 5 N/mm
  (180° peel test on soldered ribbons)
- Efficiency: > 24.7% on an industrial precursor, monofacial, 4BB



- Excellent module stability:
  1-cell GG modules, 4BB with soldered ribbons: tested until > 500 TC (-2.3%) and > 3000 h DH (-2.8%)
- SmartWire Interconnection:
  Busbar-less cells with pure copper seed layer
  Stability exceeds 3x the IEC 61215 norm
- Process applicable on aluminum zinc oxide [1]

[1] A. Lachowicz et al., Silver- and Indiumfree Silicon Heterojunction Solar Cells, EU PVSEC 2020

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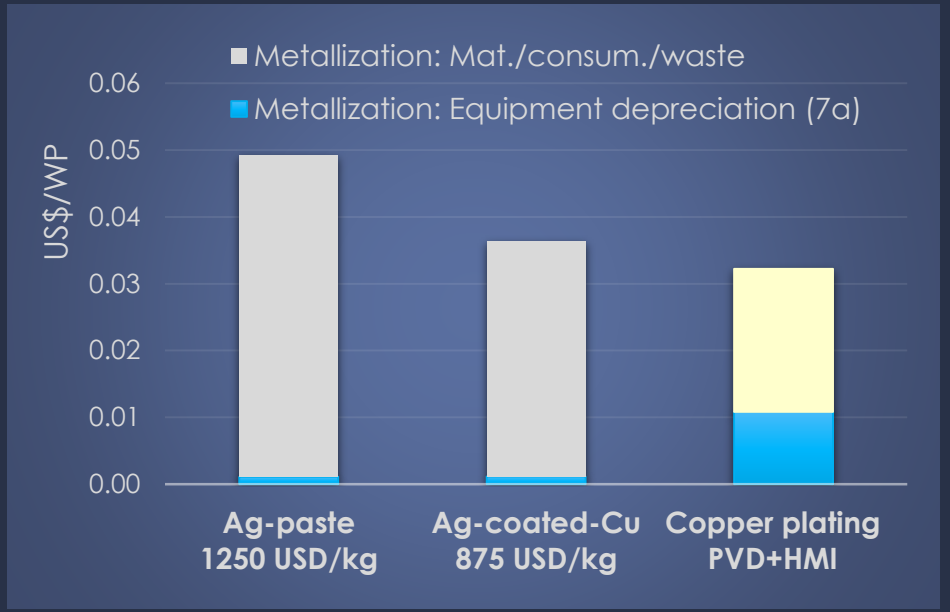
Cost comparison with screen printing

- Screen printing:
  - Bifacial HJT cells with busbars: high paste consumption, increasing silver paste price
  - Assumption for the future: cost savings of around 30% possible with silver coated copper paste



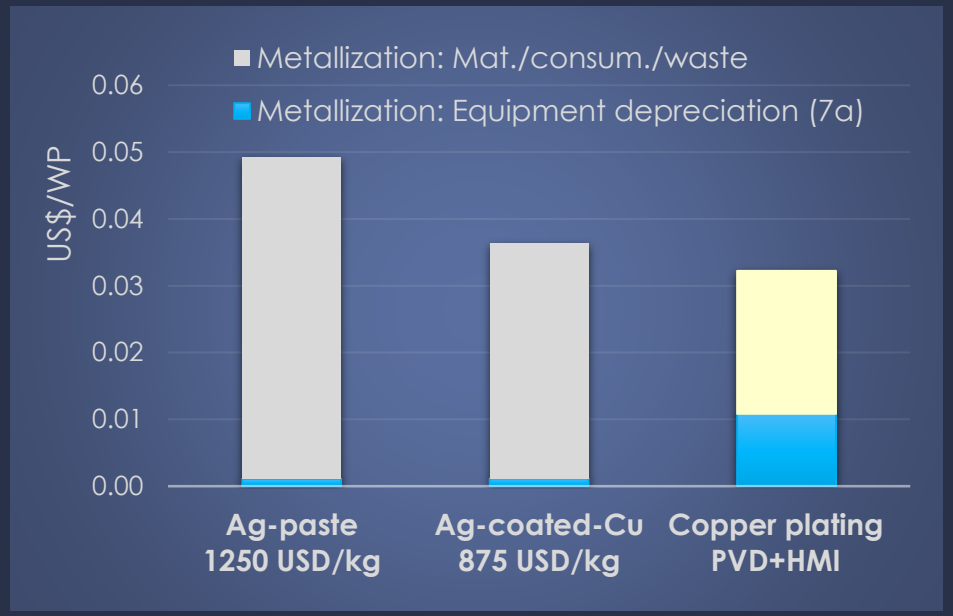
Calculatiom with **180 mg paste laydown** for bifacial HJT cells with 9 busbars
Current **silver paste** price: 1100 – 1400 US$/kg
Mean value: 1250 US$/kg

Assumed price of silver coated copper paste in the future:
70% of the current silver paste price.
Calculation with the mean Ag-paste price: 875 US$/kg

Simplified calculation: only equipment depreciation and material cost considered. Facility and labor related cost not included.

Cost comparison with screen printing

- Screen printing:
  - Bifacial HJT cells with busbars: high paste consumption, increasing silver paste price
  - Assumption for the future: cost savings of around 30% possible with silver coated copper paste
- Reference plating process
  - Higher upfront investment: PVD, inkjet printer, plating line
  - Organic mask: currently high material cost, considered to decrease with increasing production volumes
  - Process planned for implementation in production at a HJT manufacturer
- Research focus:
  - Further cost reduction - replacement of the PVD seed layer and different masking materials



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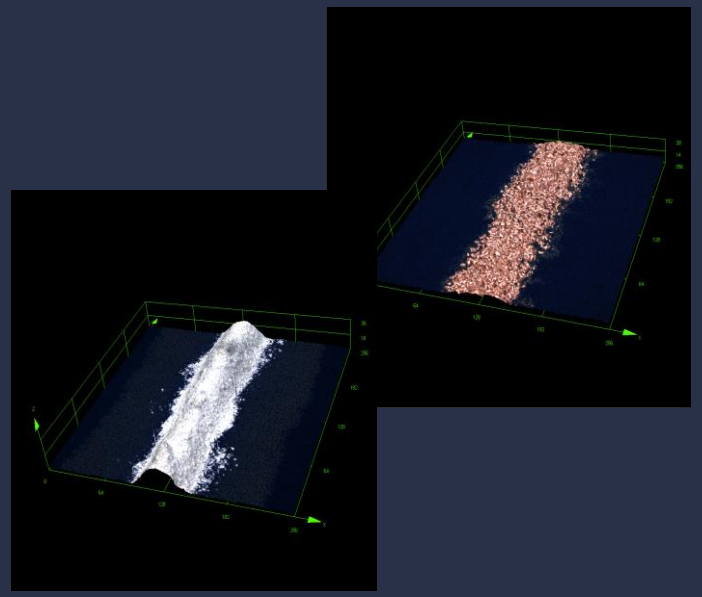
Self-aligned process: printed seed-grid and thin masking layer

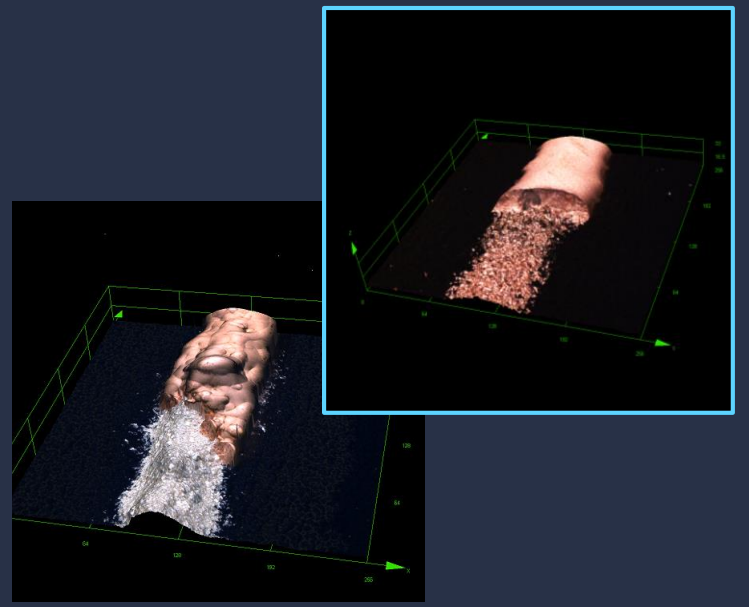
- Short process sequence

Screen printing → **Mask deposition** → **Copper plating**



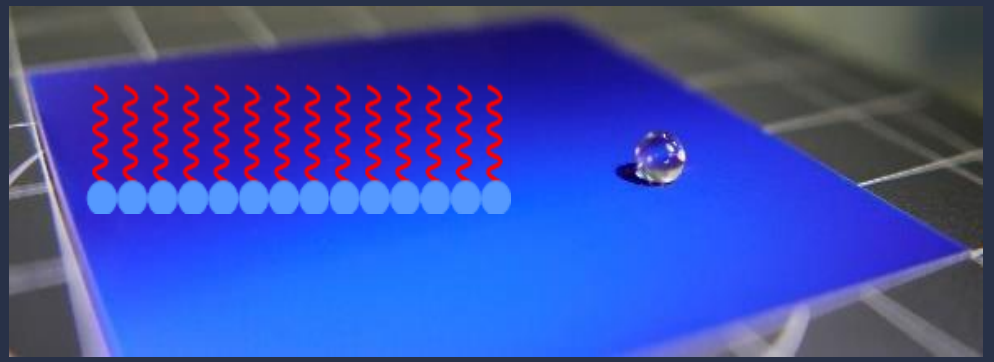
SiN_x / SiO_2 / SiO_xN_y
Al_2O_3
SAMs

SAMs = Self-assembled monolayer of organic molecules

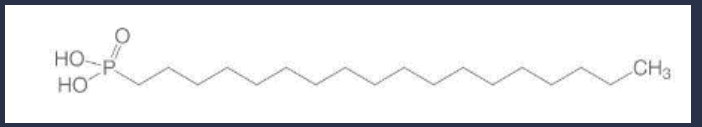


Masking layer: self assembling molecules

- Commercially available octadecyl phosphonic acid (C18-PA) and perfluorinated phosphonic acids are applied on M2 wafers by spraying
- Bonding of the phosphonic group to ITO and formation of a well-ordered monolayer occur during subsequent annealing step.
- Hydrocarbon chains form a highly hydrophobic layer protecting the wafer surface against the copper electrolyte



C18-PA



[1] G. Andreatta et al., Thin Solid Films, 2019
[2] A. Lachowicz et al., EU PVSEC, 2020

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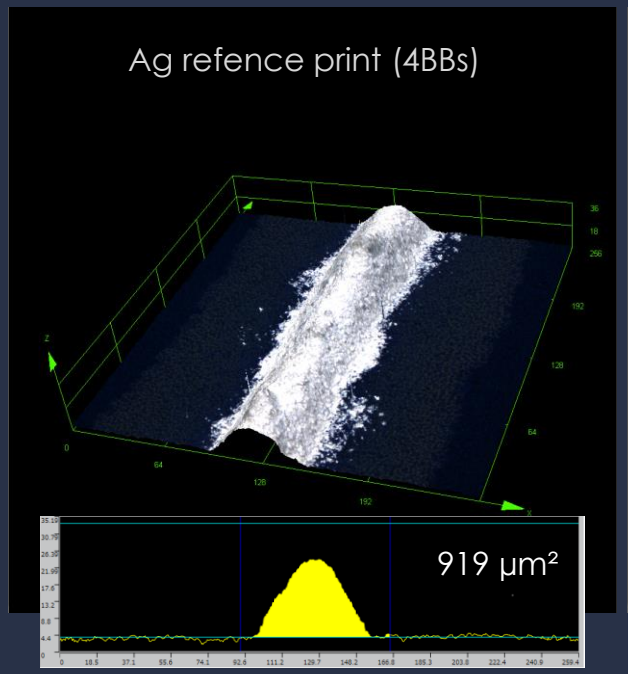
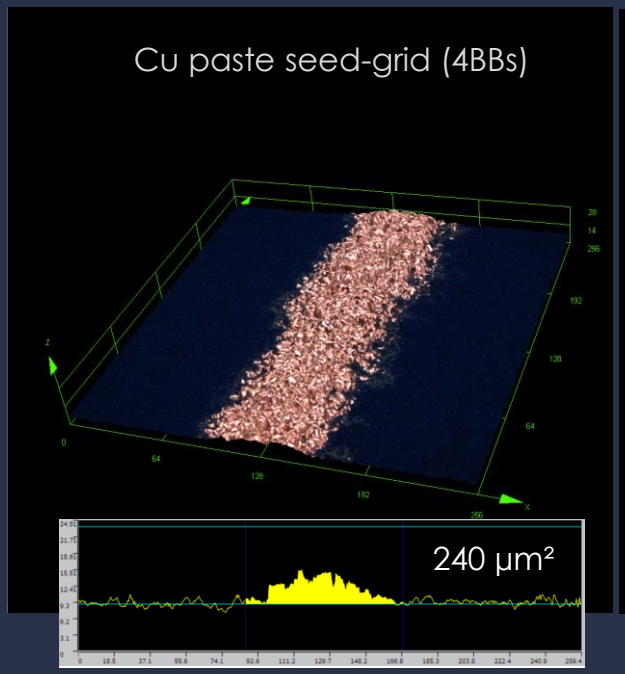
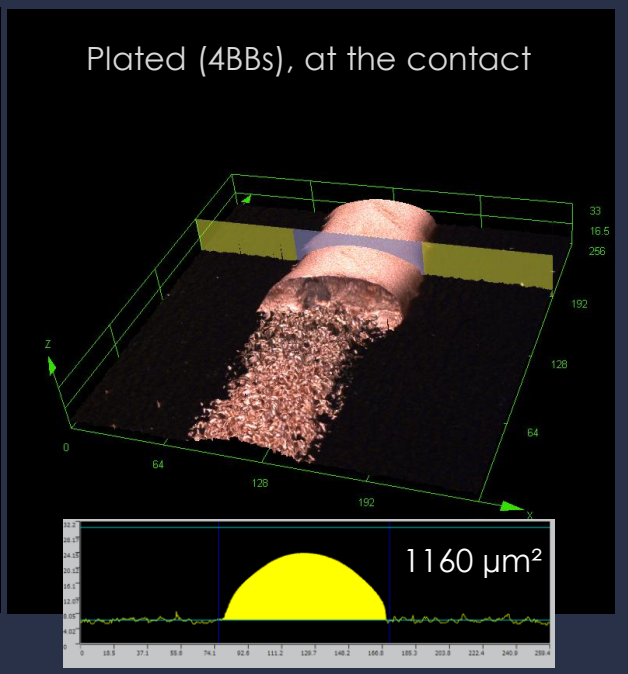
Grid dimensions and line resistance



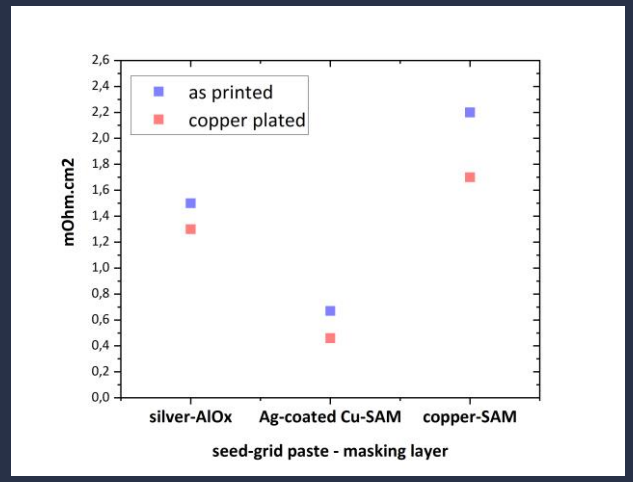




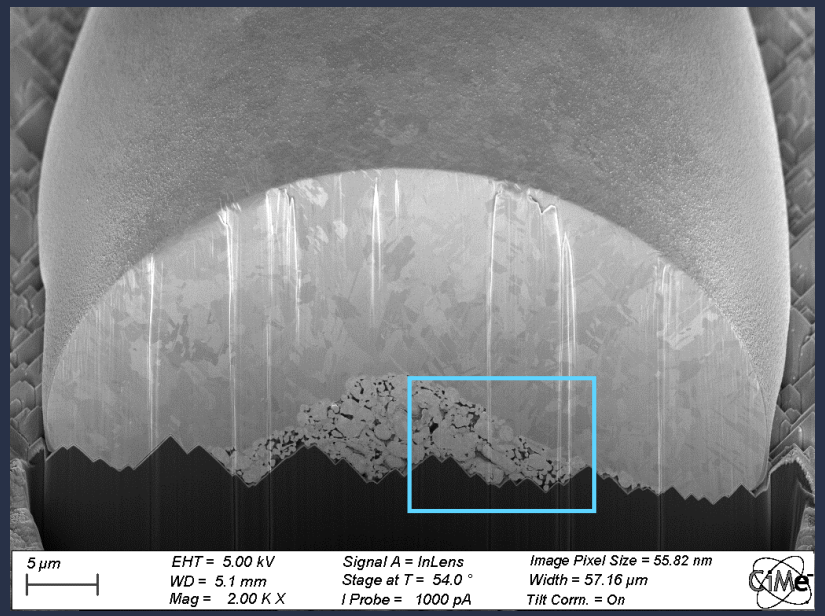
		Ag grid	Cu grid	Cu plated
Specific resistivity	[µΩ·cm]	5.3	27	2.0
Line resistance per length unit (40 µm screen opening)	[Ω/cm]	1.5	95	0.3

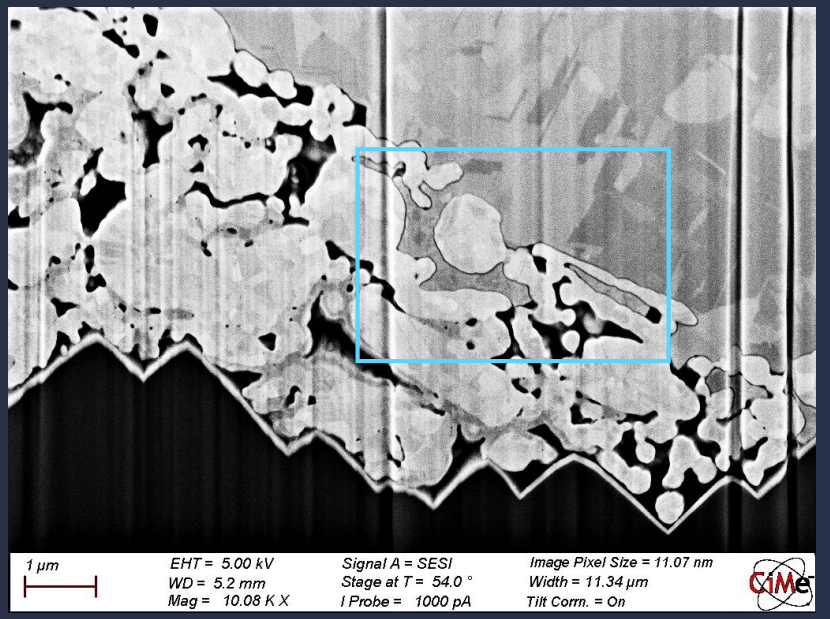
Contact resistance

- Lower contact resistance with plated copper than measured directly on printed seed-grid
- Copper is electrodeposited not only on the surface of the grid line but also in between the paste particle

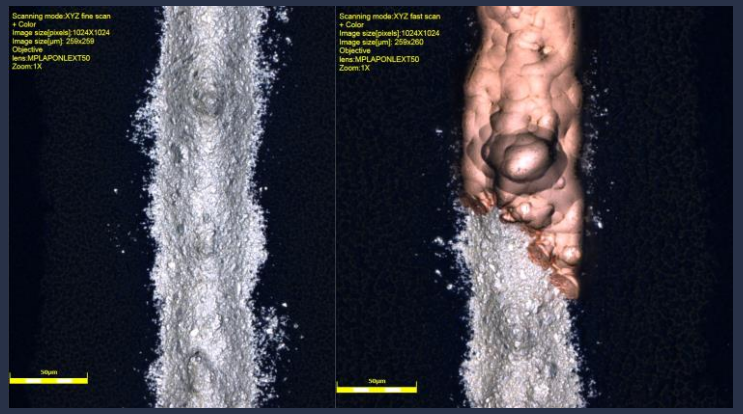


Copper electrodeposited on Ag-paste seed-grid with ALD-AlOx mask 8 nm

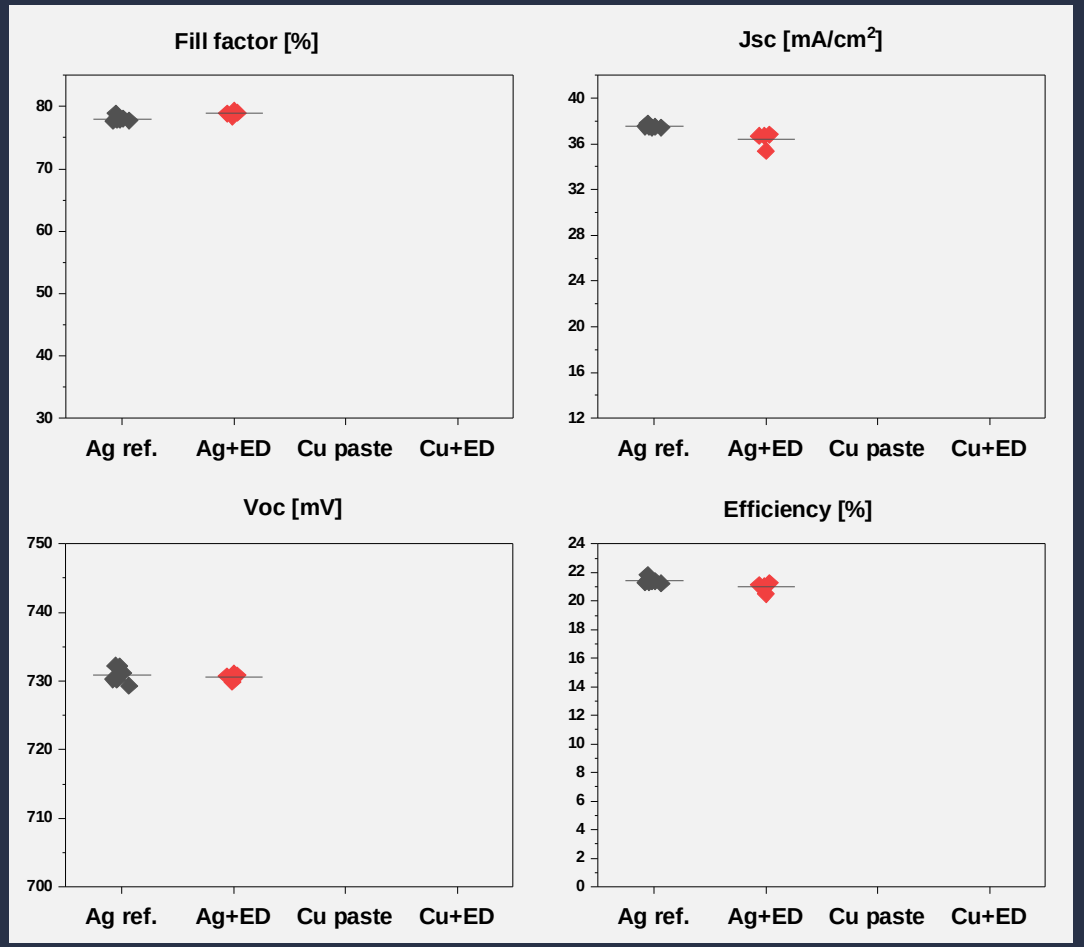




Cu plated on seed-grid: IV



- Bifacial cells with 4 busbars
  on medium quality external precursors M2
- Plating mask: SAMs



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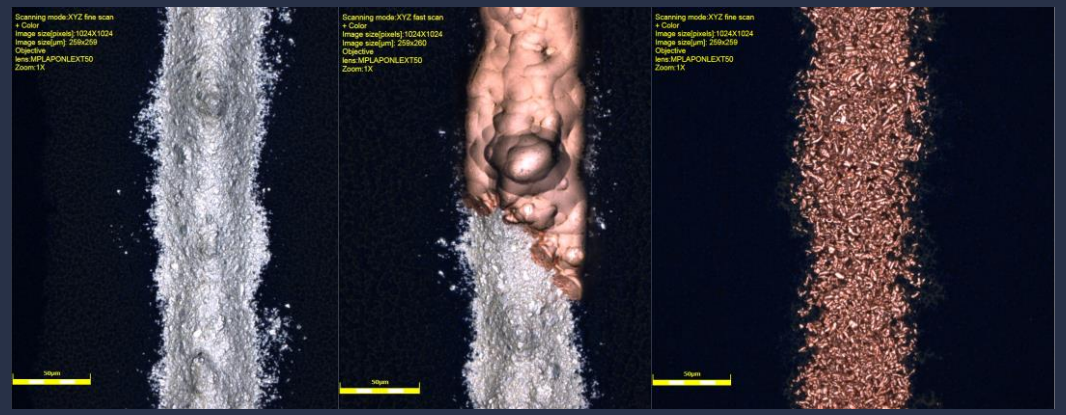

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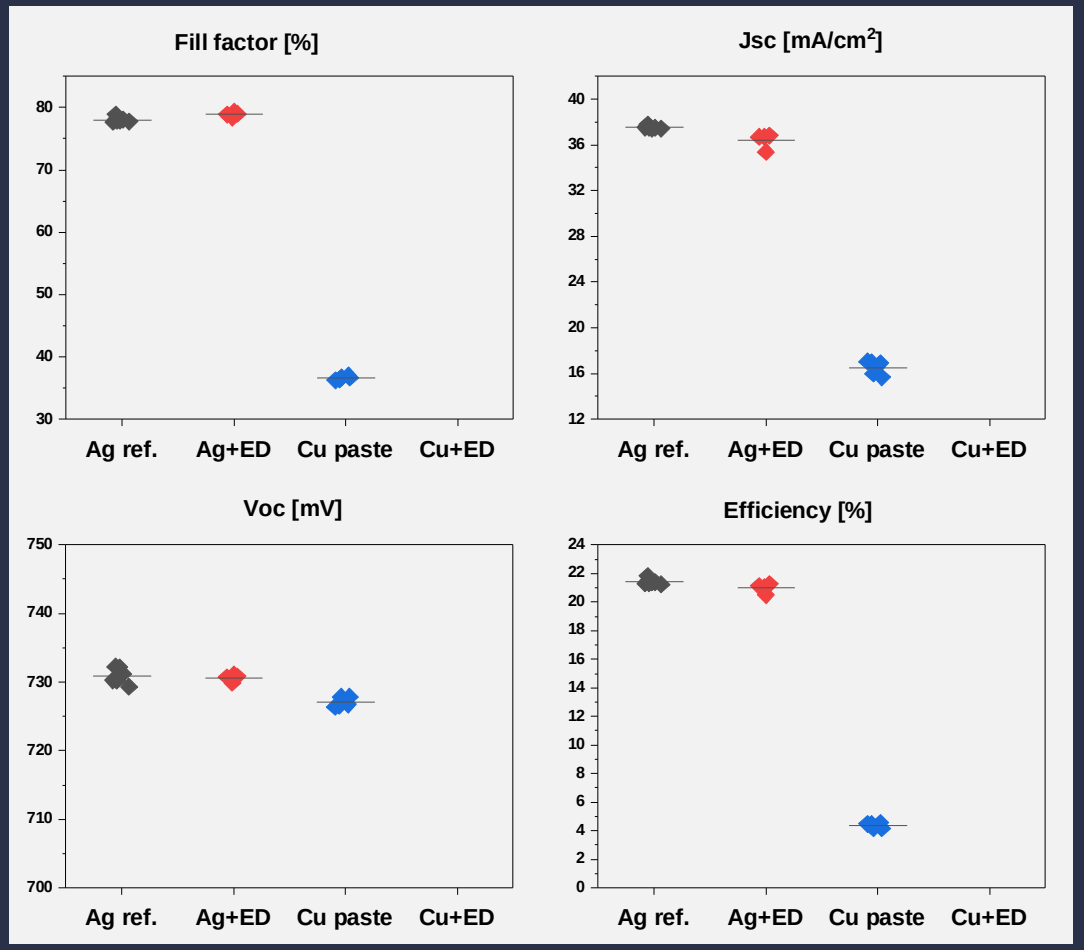

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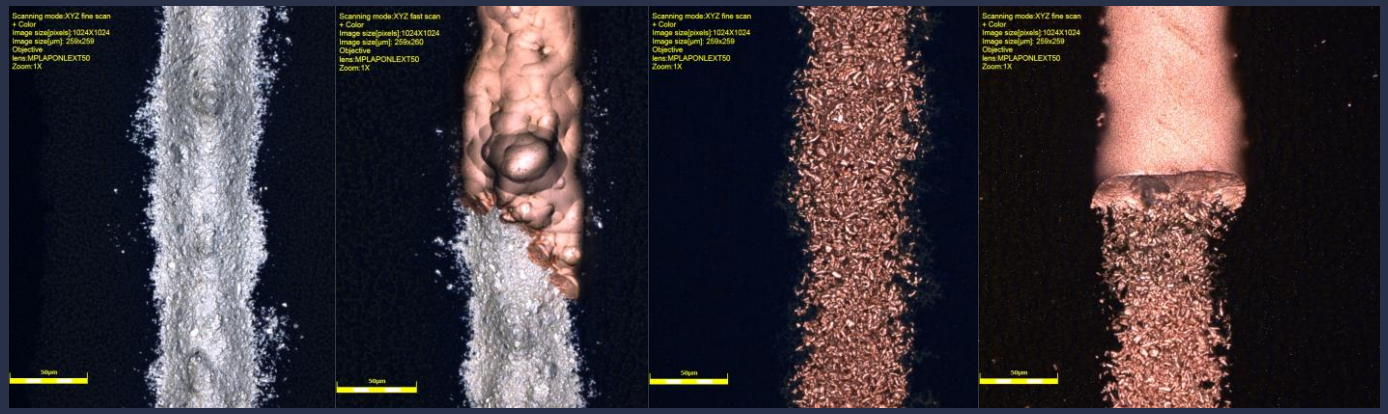
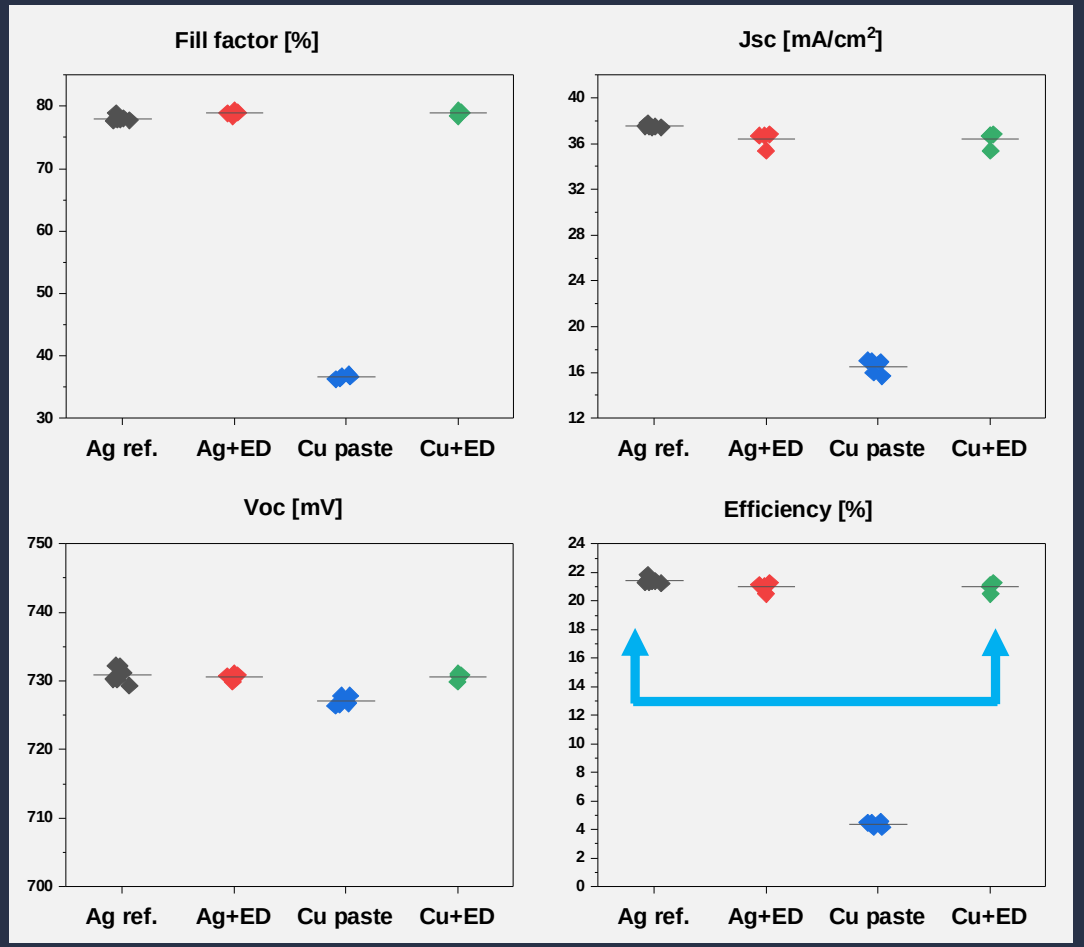
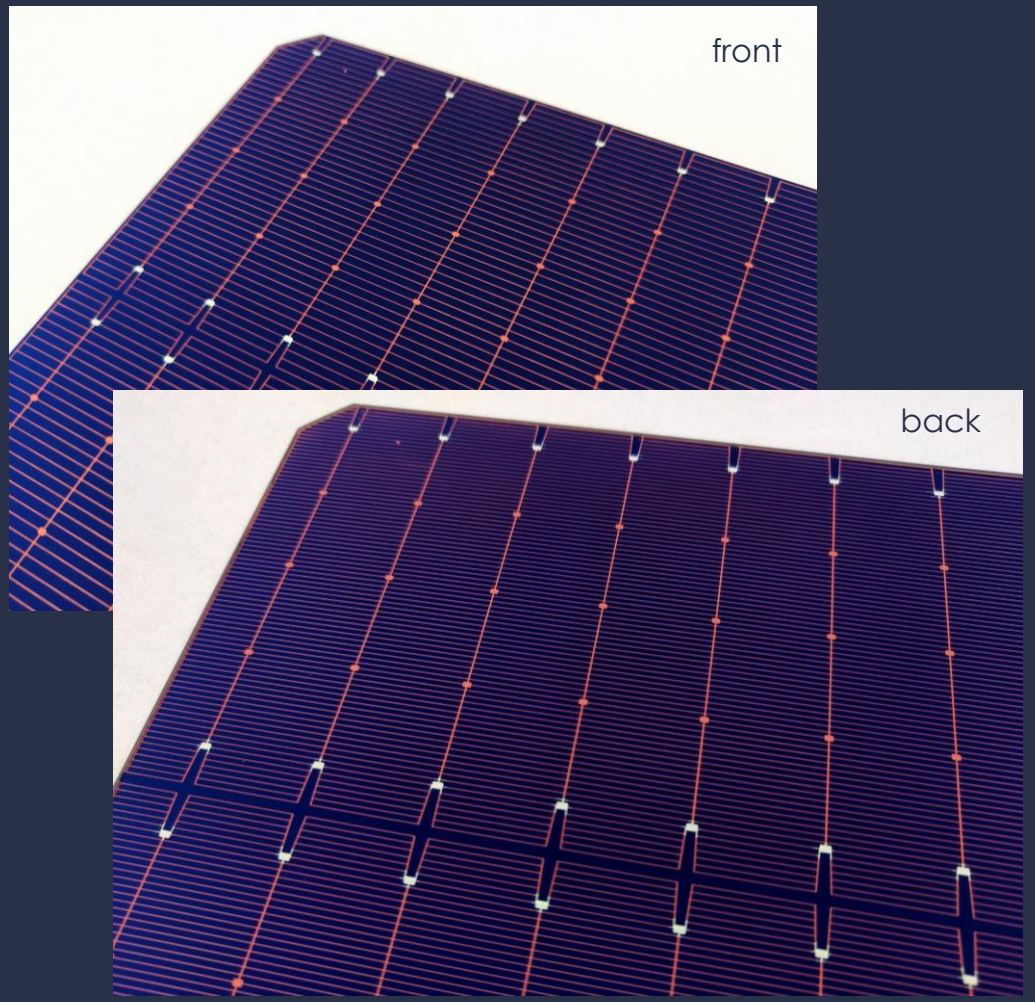




- Bifacial cells with 4 busbars
  on medium quality external precursors M2
- Plating mask: SAMs
- Same efficiency as Ag reference reached
  with pure Cu paste and electrodeposited Cu
  Next step: narrower lines and module integration.

Process test on M6 cells with half-cell layout

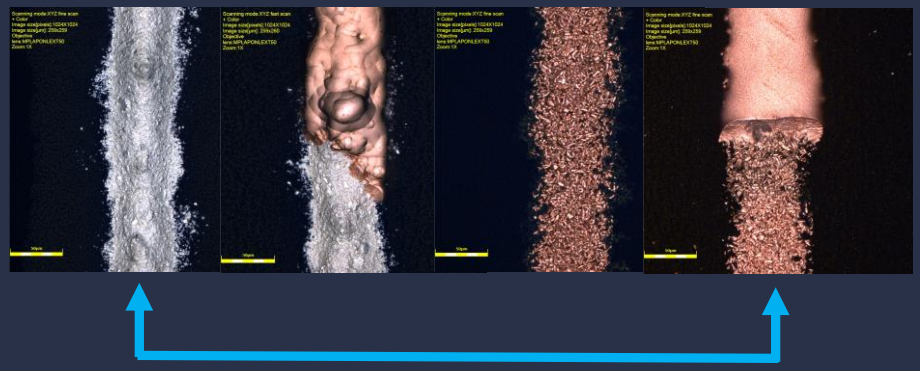
- Test on standard production cells with Ag paste grid and 9BBs (from a HJT manufacturer)
  Busbar-pads used for contacting
- Simultaneous plating on both sides
- Isolated contacts at the edges and on the surface of the wafer
  Additional mechanical stabilization for bigger wafers through contacting bars in the center
- Contacting system applicable on M10 and G12
- Suitable for thin wafers: 200 cell batch of 135 µm wafers processed without breakage (bifacial industrial M2 wafers, contacted at the edges)
- Next experiments:
  - Plating on silver-coated and pure copper paste grid
  - Test on precursors with AZO and protective layer (for DH stability) [1]

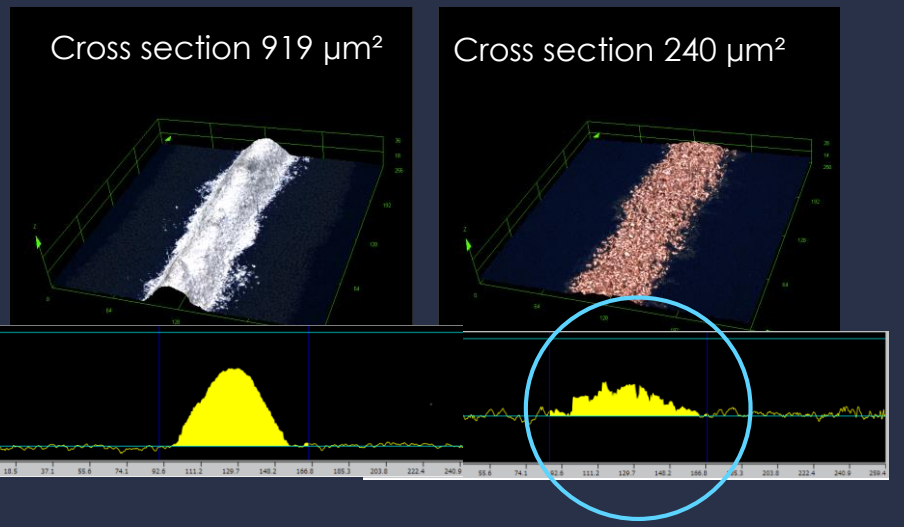


[1] B. Stannowski et al., Heterojunction Workshop, Nov. 2021

Summary

- Same efficiency with pure Cu seed-grid and electroplated Cu as with standard silver paste
  - Easy requirements on screen-printing: uniform plating feasible even on resistive lines
    Good tolerance for constrictions and thin spots
    Low paste laydown even with copper paste





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  - Easy requirements on screen-printing: uniform plating feasible even on resistive lines
    Good tolerance for constrictions and thin spots
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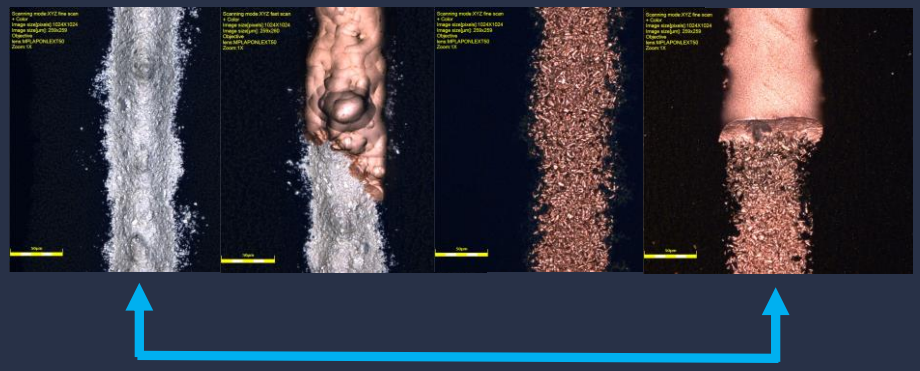
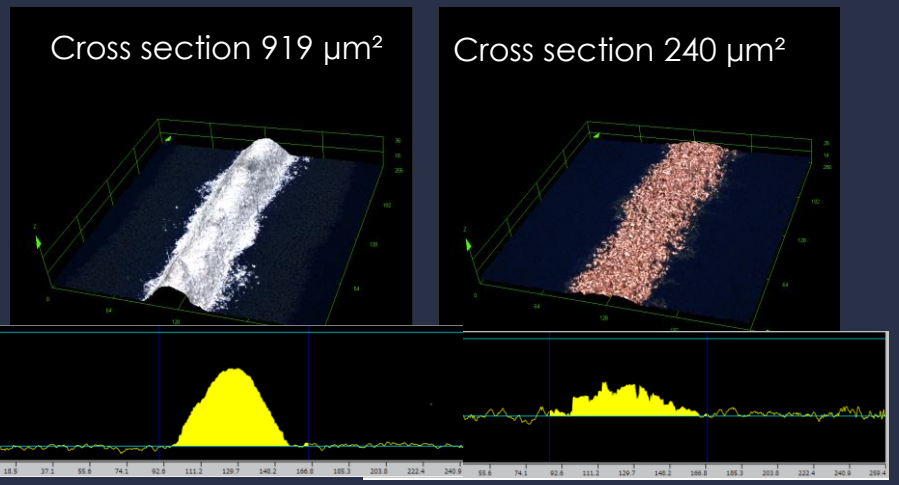
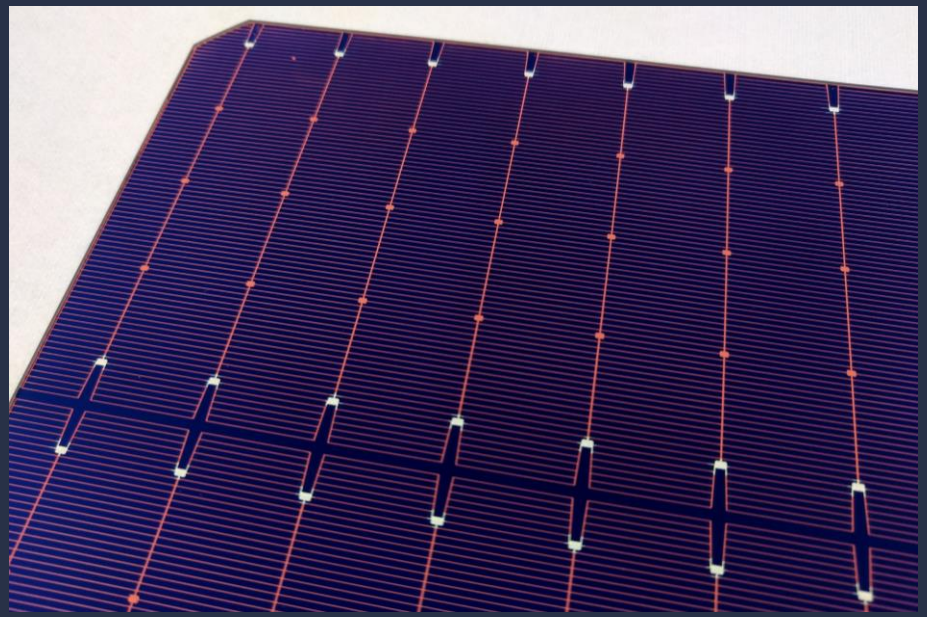
- Contacting system suitable for bifacial simultaneous plating of M6, M10 and G12 wafers with not connected grid segments and for thin wafers







Thank you very much for your attention!

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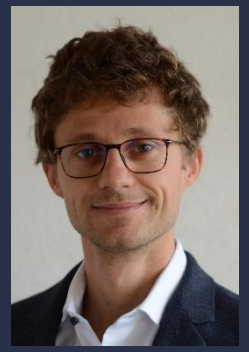

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