SILICON HETEROJUNCTION METALLIZATION AND MODULES APPROACHES

A. Faes[1*], M. Despeisse[1], J. Levrat[1], J. Champliaud[1], A. Lachowicz[1], J. Geissbühler[1], N. Badel[1], J. Horzel[1], H. Watanabe[1], J.-W. Schüttauf[1], T. Söderström[2], Y. Yao[2], J. Ufheil[2], P. Papet[3], B. Strahm[3], J. Hermans[4], A. Tomasi[5], Y. Baumgartner[5], J. Cattin[5], M. Kiaee[5], A. Hessler-Wyser[5], M. A. Modestino[5], J. Fleischer[6], P.V. Fleischer[6], A. Tsuno[7], C. Ballif[1,5].

1. CSEM PV-Center, Neuchâtel, Switzerland, Tel : +41 32 720 56 33, *Contact: antonin.faes@csem.ch
2. Meyer Burger AG, Thun, Switzerland.
3. Meyer Burger Research, Hauterive, Switzerland.
4. Meyer Burger B.V., Eindhoven, Netherlands.
5. EPFL, PV-Lab, Neuchâtel, Switzerland.
6. PVF-Vertriebs GmbH, Neufinsing, Germany.
7. NAMICS Corporation, Niigata City, Japan.

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Si Heterojunction Cells: Fabrication Sequence

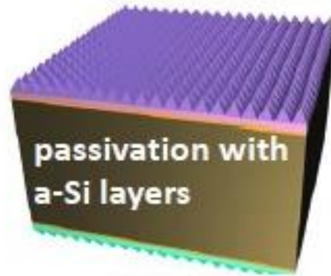
Chemical baths
c-Si surface preparation

PECVD I
Intrinsic film deposition *a*-Si:H(*i*)

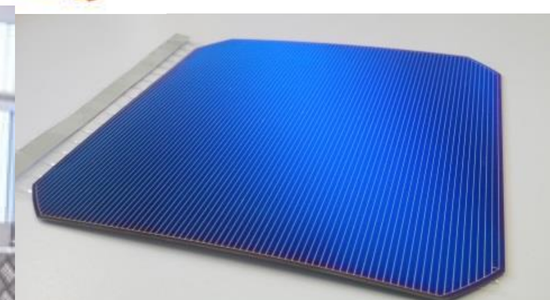
PECVD II
Doped film deposition *a*-Si:H(*n*/*p*)

PVD
TCO sputtering

Metallization
Screen printing and curing ~200° C



THIN FILMS Stability < 230℃



How to have high bulk conductivity with low process temperature (<230°C)?

Metallization Platform at CSEM

Screen-Printing
Low temperature
Ag paste

Electro-Plating
Cu core, Ni, Ag, Sn

InkJet Printing
Ag ink, Hotmelt

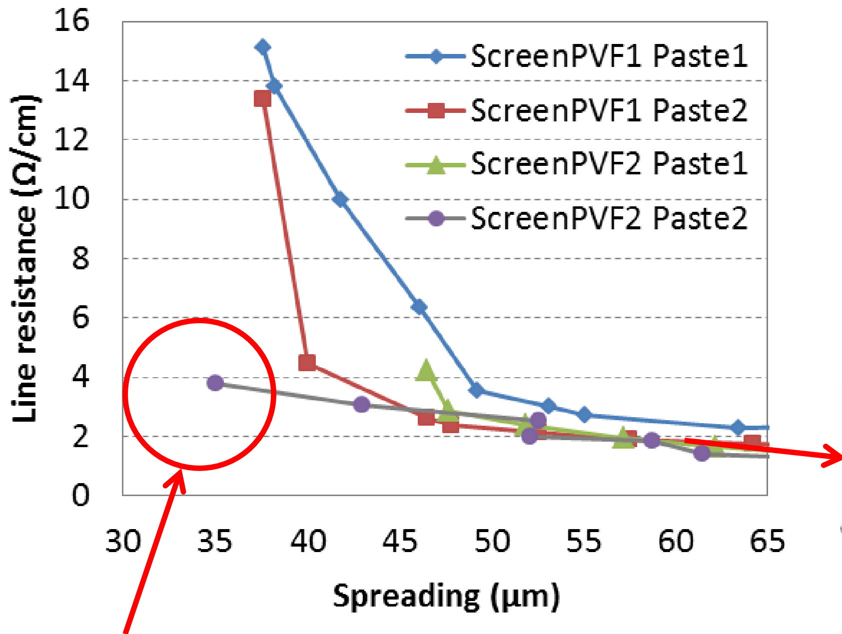
Charaterization
Line&Contact resistance,
3D microscope

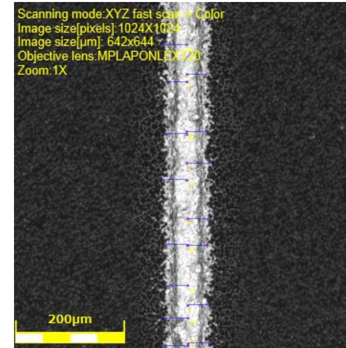
Automatic tool from Alfartec

Cell Fabrication + Simulation

3D confocal microscope
Simulation tool from CSEM

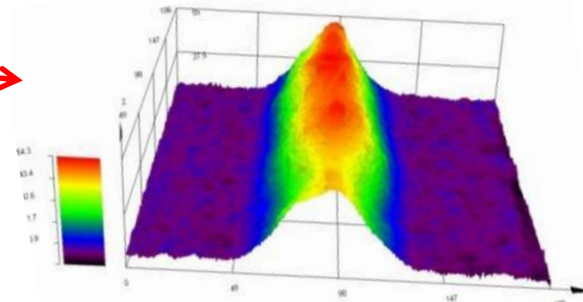
Screen-printing Optimization





Confocal images of print done with the 65 µm opening

Spreading = 80 ± 5 µm
Height = 25 ± 2 µm



Line resistance <0.35 Ω/cm

Confocal images of print done with the 20 µm opening

Spreading = 34 ± 4 µm
Height = 6 ± 2 µm

Line resistance <4 Ω/cm

Bulk resistivity ~ 5 - 7 µΩ.cm

210°C 30min

Tests were made with MICRON®-screens by PVF

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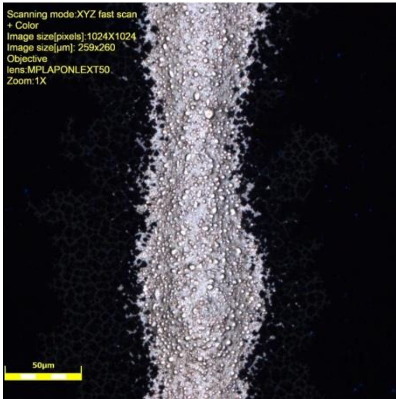
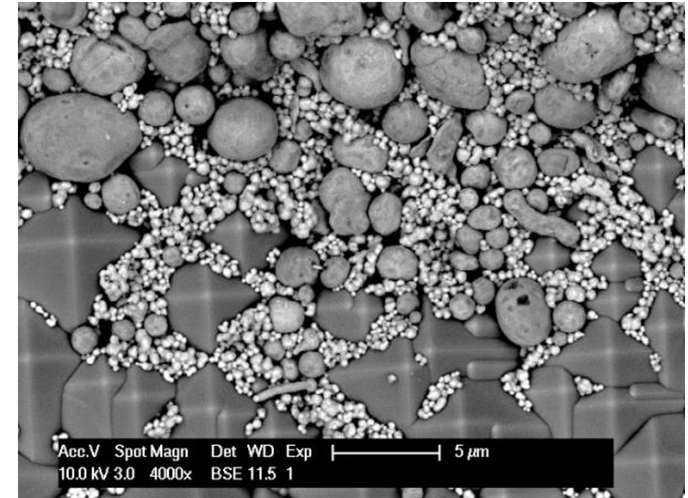
NAMICS

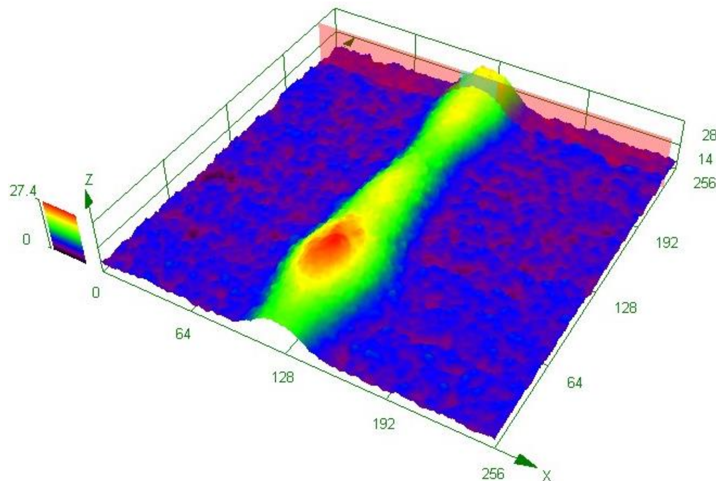
Copper paste

Paste and Print results



- Copper-based paste for Screen-printing from NAMICS Corp.
- Finger spreading = 59 µm
  Finger height = 14.5 µm
- Finger line resistance = 4.5 Ω/cm





Bulk resistivity ~ 23 µΩ.cm

210°C 30min in N_2

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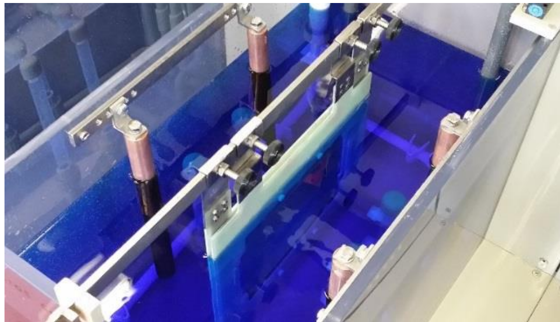
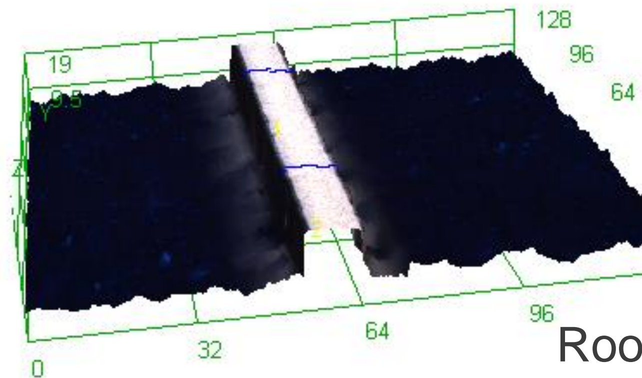
Copper plating: equipment + process

Pilot-demo vertical line

- Direct plating, Light induced plating, plating on seed
- Bifacial plating
- Ni, Cu, Sn, Ag plating solution





Width[µm]	Height[µm]
15.6	9.8

Room Temperature, wet process

Bulk resistivity ~ 1.8 - 2 µΩ.cm

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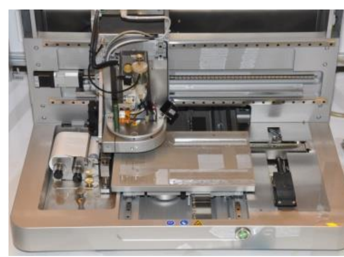
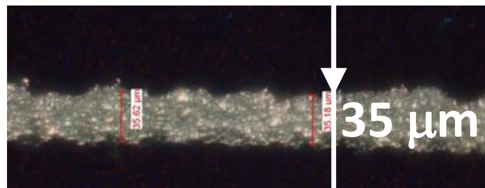
Ag Ink-jet printing



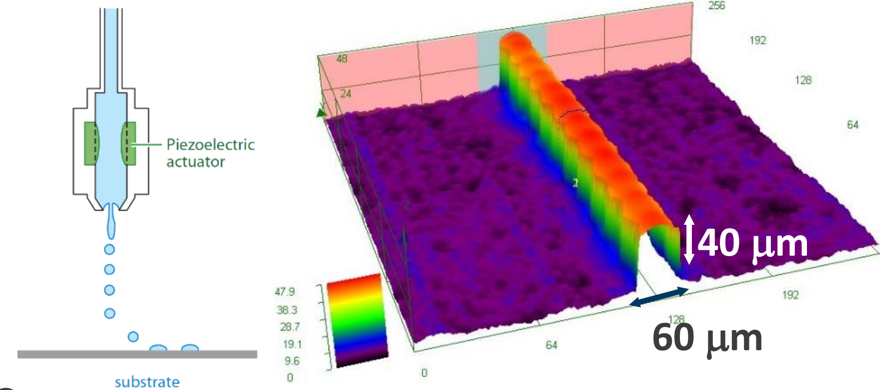
Direct metallization

- Printing strategies **optimization**
- **35 μm width finger** (thin deposit)
- 60 μm width finger with aspect **ratio of 0.7**
- Resistivity: ◦ 320 μΩ.cm after 20 min at 100°C
  ◦ 6 μΩ.cm after 60 min at 200°C
- Cost of **nano-ink** is relatively high

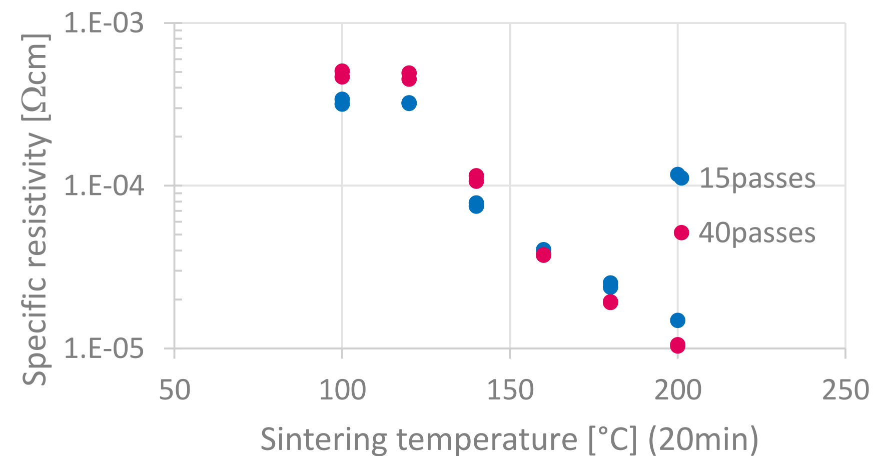


Bulk resistivity ~ 6 μΩ.cm

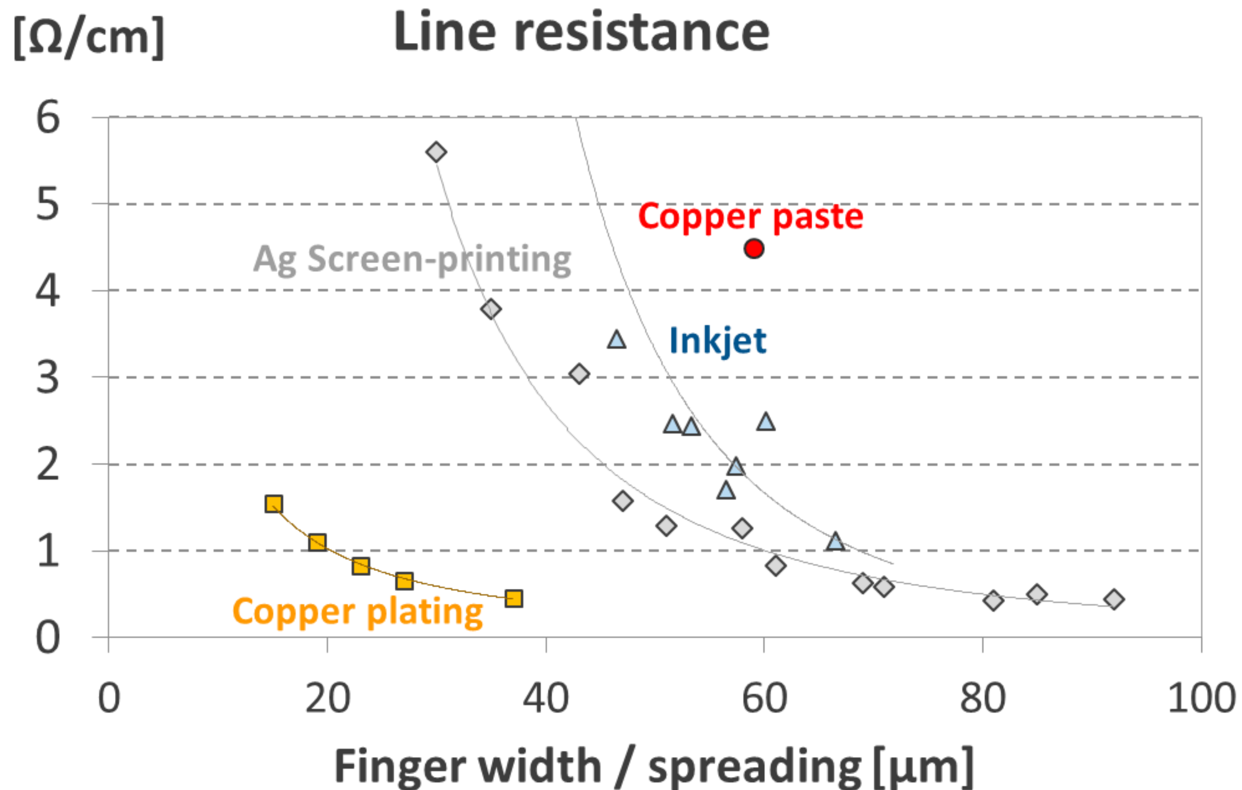
200°C 60 min



Width[μm]	Height[μm]	CS area[μm²]
60.4	40.4	880



Summary Metallization for SHJ Solar Cell



- Cu plating : fine line with high conductivity
- Inkjet printing: cannot go below 1 Ω/cm

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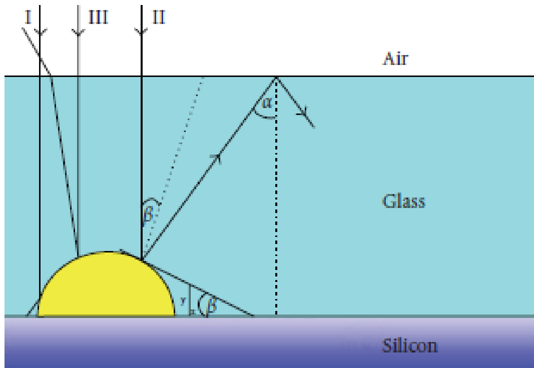
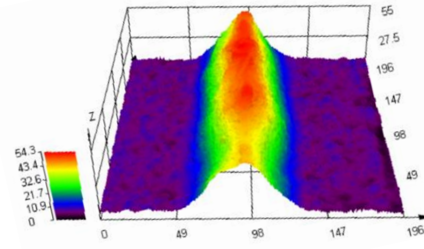
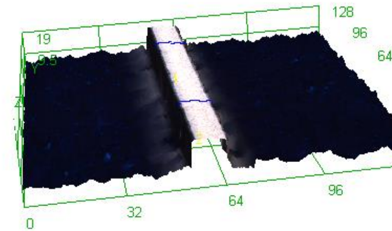
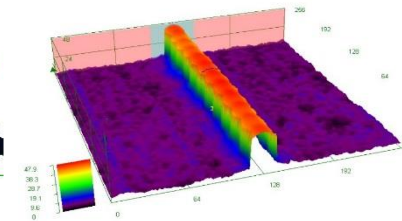
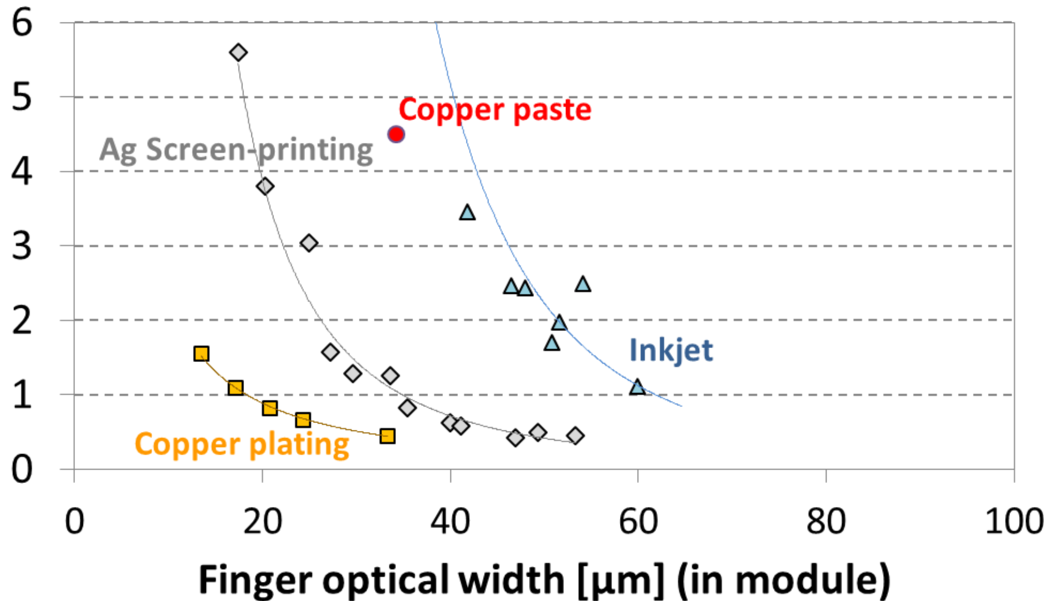
What will happen in the module?

Metallization Optical Gain



R. Woehl *et al.*,
Advances in OptoElectronics, vol. 2008 (2008)

	Screen-printing	Cu plating	Inkjet printing
			
Effective Optical Width	**60%**	90%	90%
	Measured + simulated	simulated	simulated



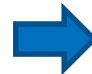
In module, Screen-printing shadowing is reduced and closer to Copper Plating

Power losses and module integration

Higher efficiency with SmartWire due to reduce losses

- Power dissipation losses in fingers (P_f) vs finger line resistance (R_f) and finger length (L_f) [1]

$$P_f = Const \cdot R_f \, L_f^2 \approx 1\%$$

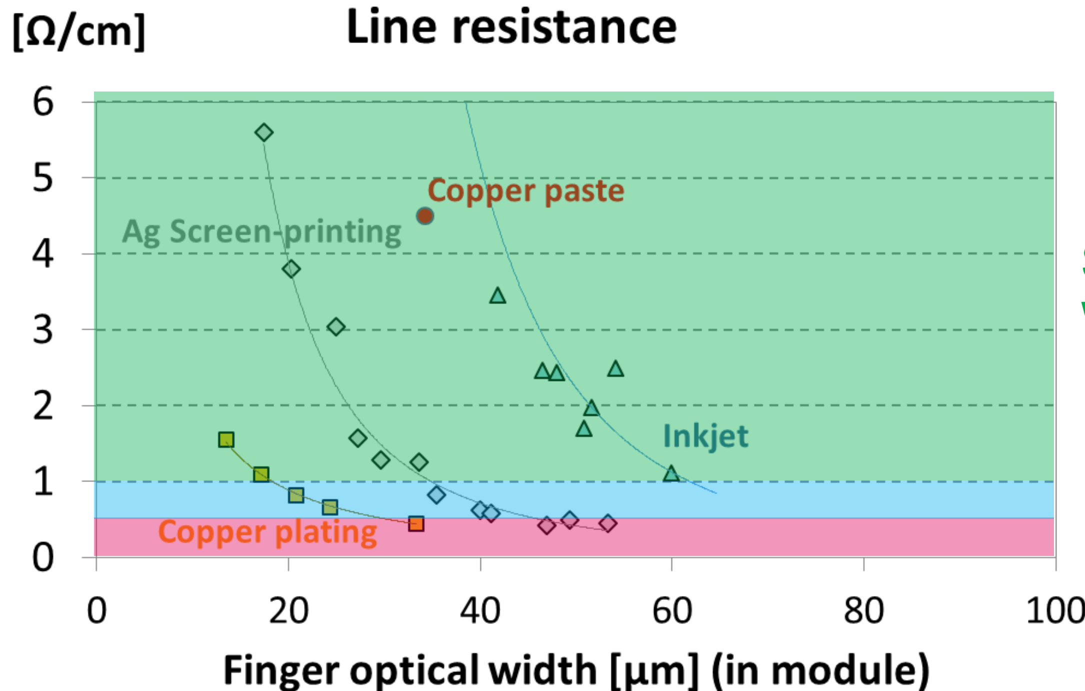


For 80 fingers

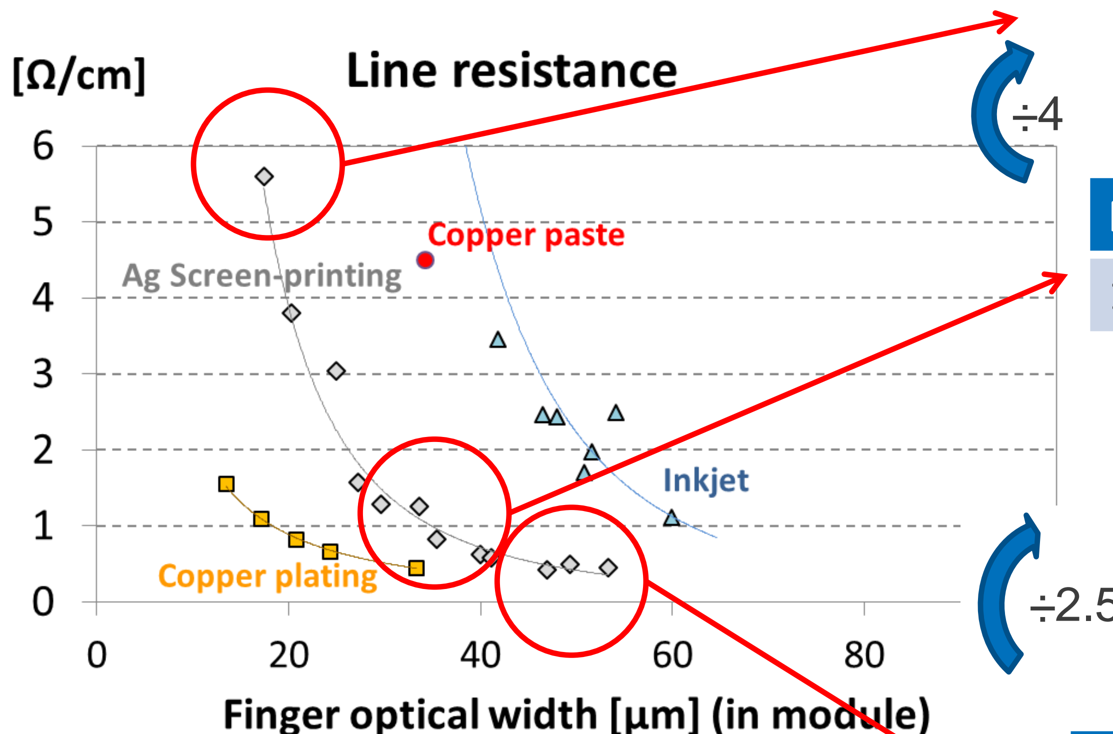
$R_{f,18wires} \approx 10 \; \Omega/cm$

$R_{f,5BB} \approx 1 \; \Omega/cm$

$R_{f,3BB} \approx 0.4 \; \Omega/cm$



Ag deposited weight



Front	Bifacial
25 mg	55 mg

Smart Wire

Ag cost = 2.7 ct€/cell

Front	Bifacial
100 mg	220 mg

5BB

Ag cost = 11 ct€/cell

Front	Bifacial
250 mg	550 mg

3BB

Ag cost = 27 ct€/cell

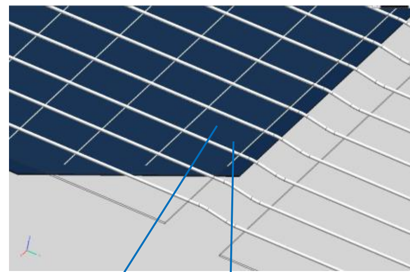
Lower cost with SmartWire due to reduce silver deposition

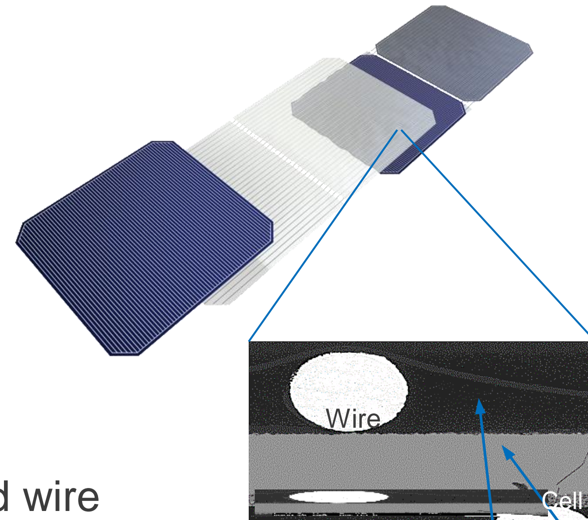
Ag price = 501 €/kg (07.10.2016)

SmartWire Concept

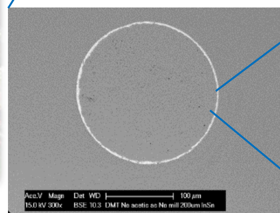
No busbar cells | **Wire interconnection** | **10 cells string** | **60 cells module**

Cell measurement GridTouch® from PASAN

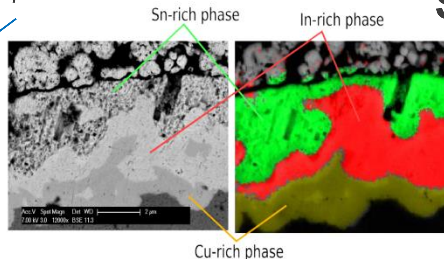




Supporting foil + adhesive



InSn Coated wire
T_f=120°C



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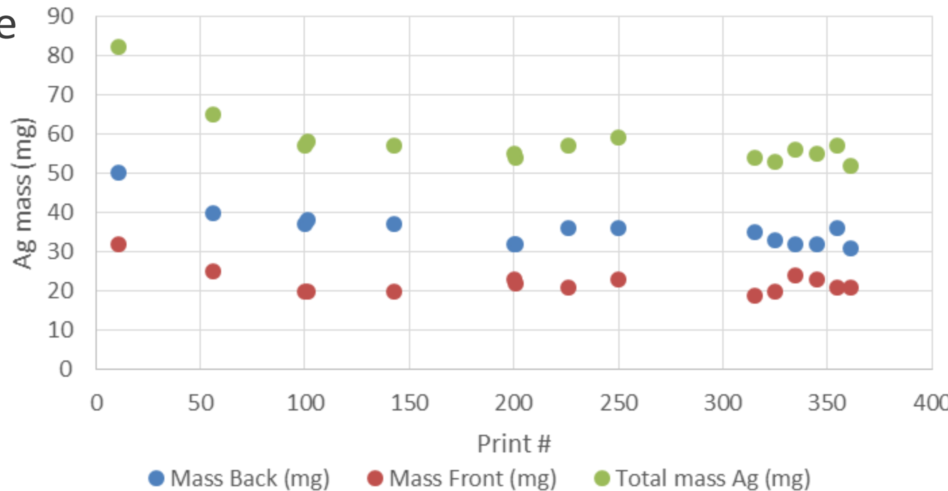
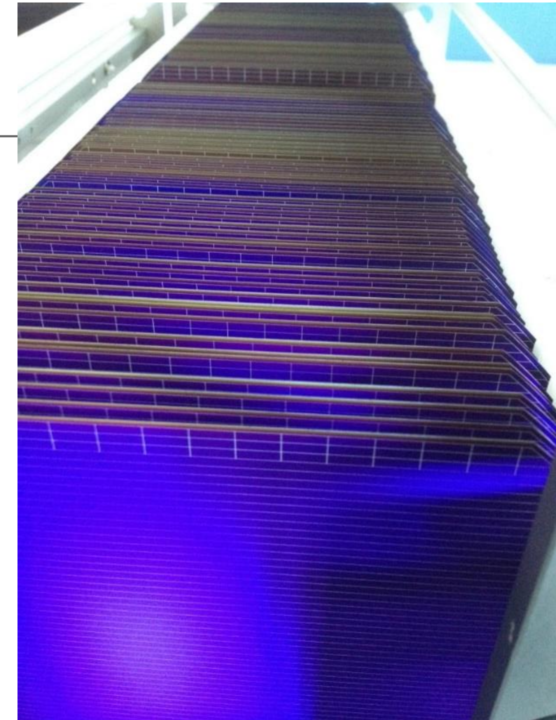
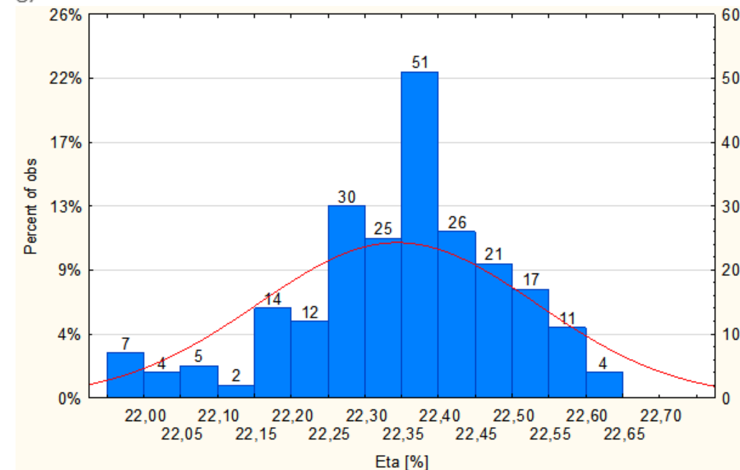
Screen-Printing in Pilot Production

- **55 mg Ag in total** for bifacial cells in pilot production line





- **43 µm line width** at the back and 48 µm line width at the front
- **Average Eff = 22.4%**



Cost of silver* for 55 mg/wafer of silver paste = 0.6 €ct/Wp (1.7 €/module)

*Silver price = 501 €/kg (07.10.2016)

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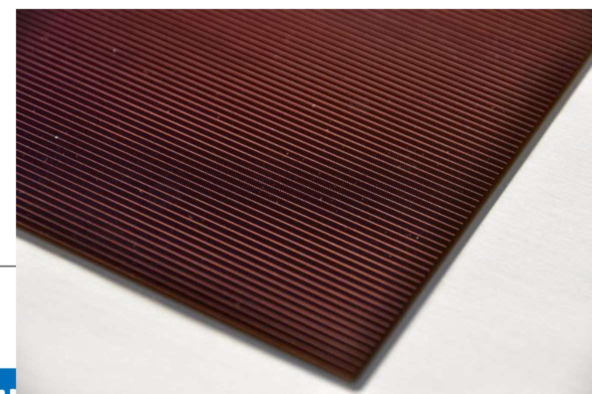
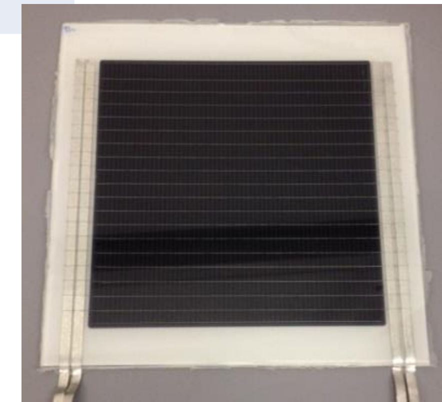
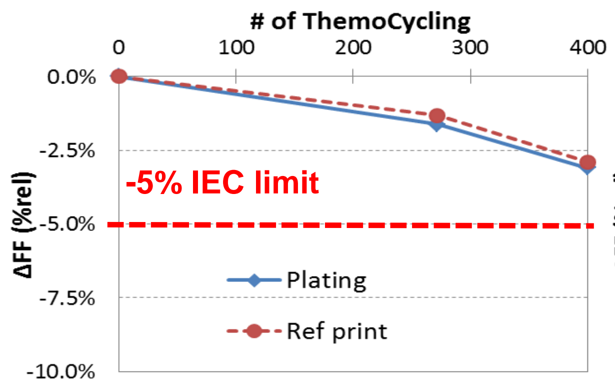
Busbar-less cells and SmartWire module

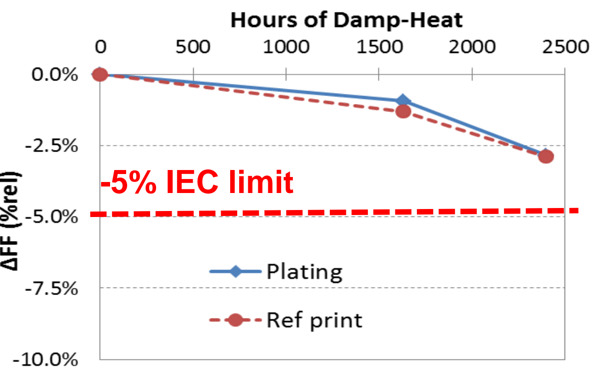


Metallization	Cell Efficiency* (%)	Module Reliability
Ag Screen-printing	**22.7**	**4x** IEC standard
Cu Screen-printing	**22.4**	**1x** IEC standard
Cu plating	**22.8**	**2x** IEC standard
Inkjet printing	**22.4**	**1x** IEC standard

Record power module 60 cells HJT = 330 Wp







- 1x IEC standard →
- 200 Thermocycling between -40°C and +85°C
- 1000 hours in damp-heat 85°C and 85% relative humidity

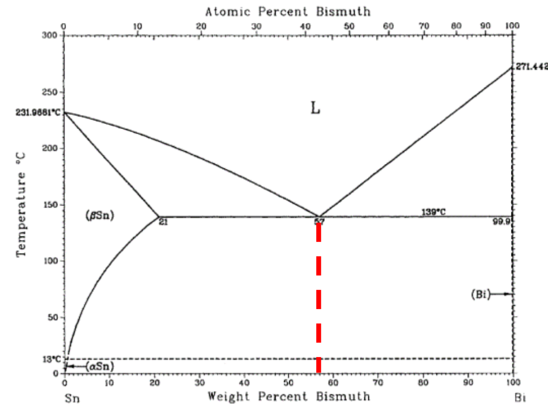
*Cell Efficiency measured with GridTouch

How to further reduce cost?

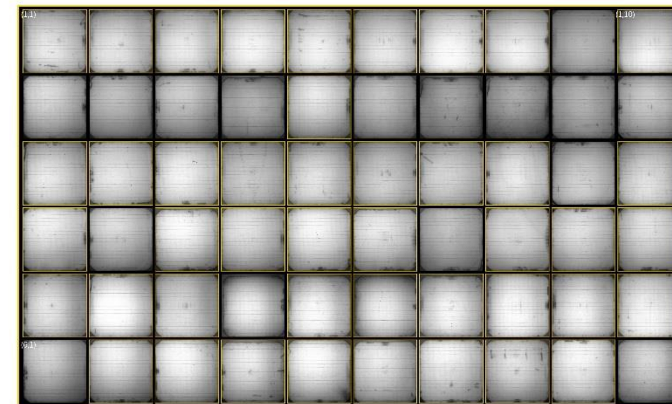
No Indium

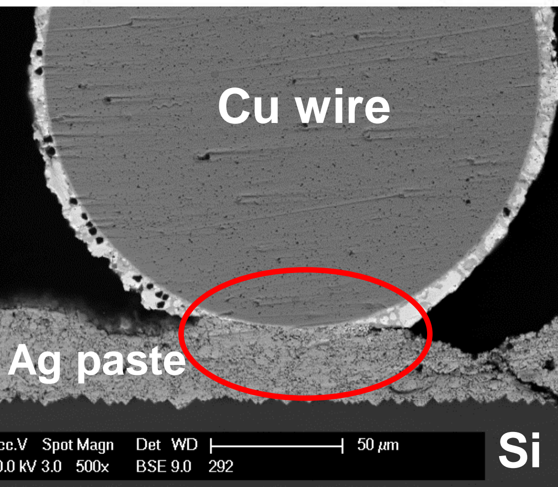
New Indium-free coating for SmartWire

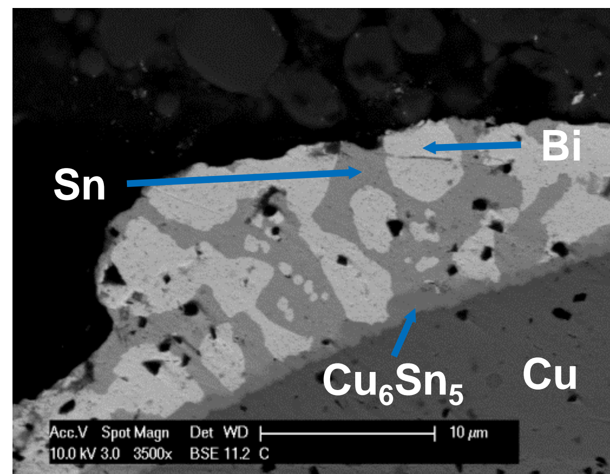
- Price cheaper than InSn ➡ only 0.25 €ct/Wp
- BiSn-based solder
- CTE close to pure Cu
- BiSn contact to Cu:
  - Cu_3Sn
  - Cu_6Sn_5



Module	FF (%)	Isc (A)	Voc (V)	**Pmax (W)**
60 cells	77.2	9.01	44.1	**307**







Pass 3x IEC
600TC & 3000h DH

With less that 3% degradation in power

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How to remove cell metallization?

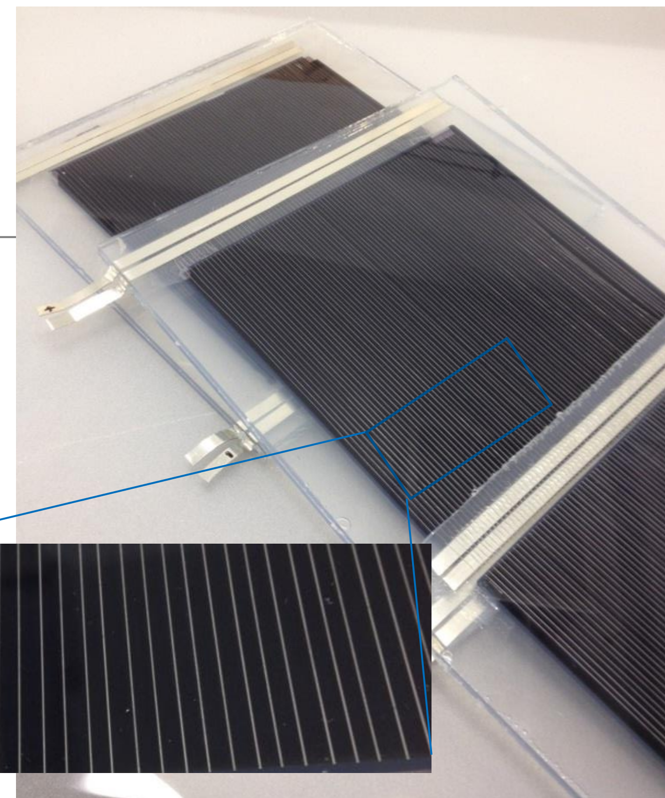
No Fingers

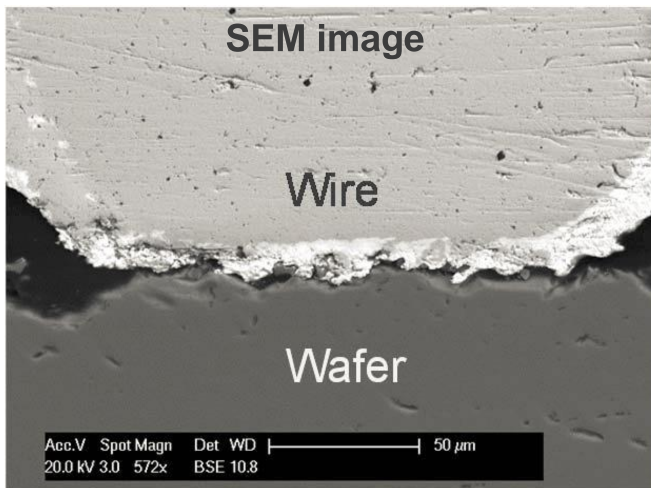
No Metallization

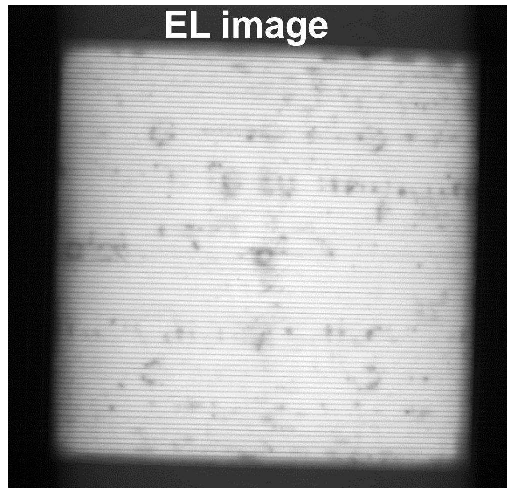
- Direct contact between InSn wire coating and TCO from the cell

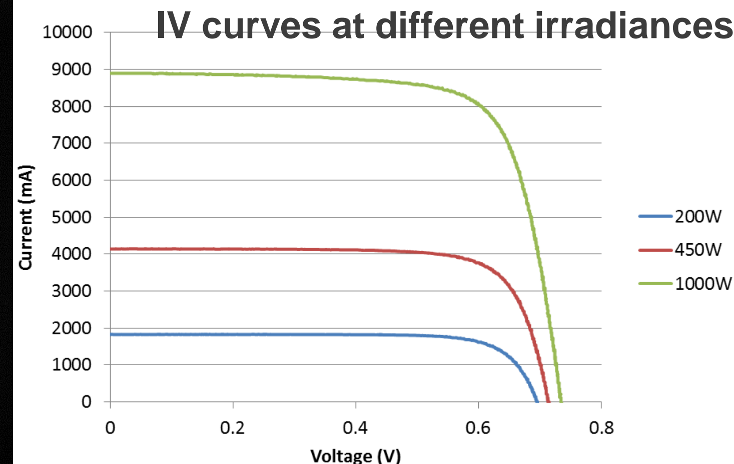
Irradiance	Voc (V)	Jsc ($mA.cm^{-2}$)	Module eff (%)	FF (%)
200 W/m²	0.696	7.73	20.6	77.8
450 W/m²	0.714	17.40	20.7	76.5
1000 W/m²	0.734	37.30	**19.9**	74.0

Module without metallization at 19.9 % eff.









CSEM acknowledge Choshu Industry Co for cell precursors

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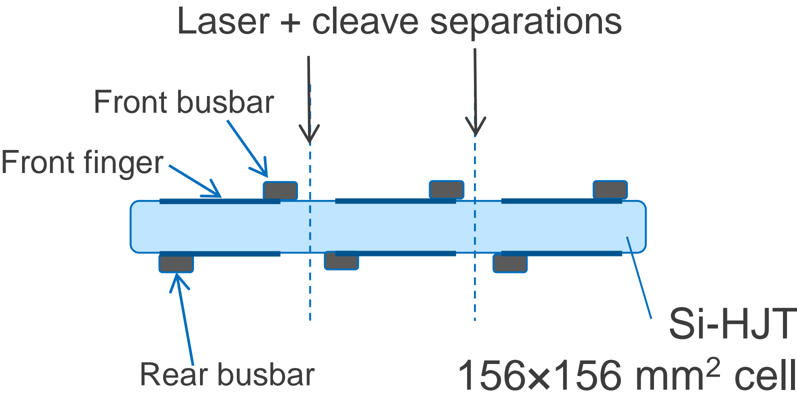
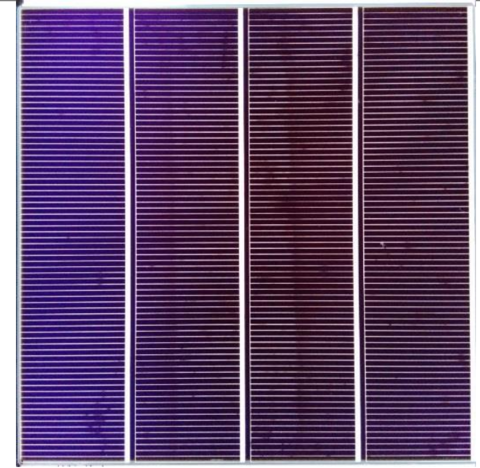
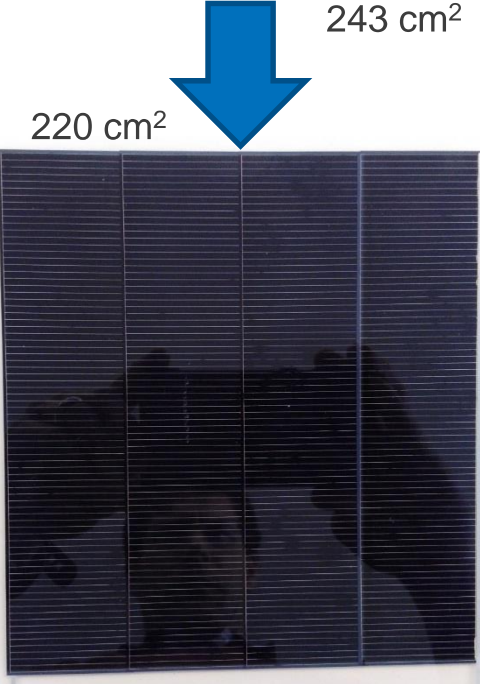
How to remove wire or ribbon interconnection?

No Ribbons nor Wires

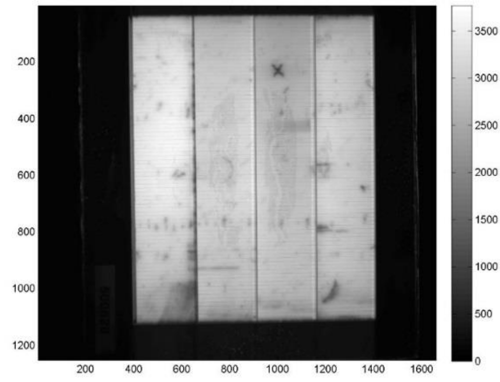
Module with Shingle Cell Interconnection





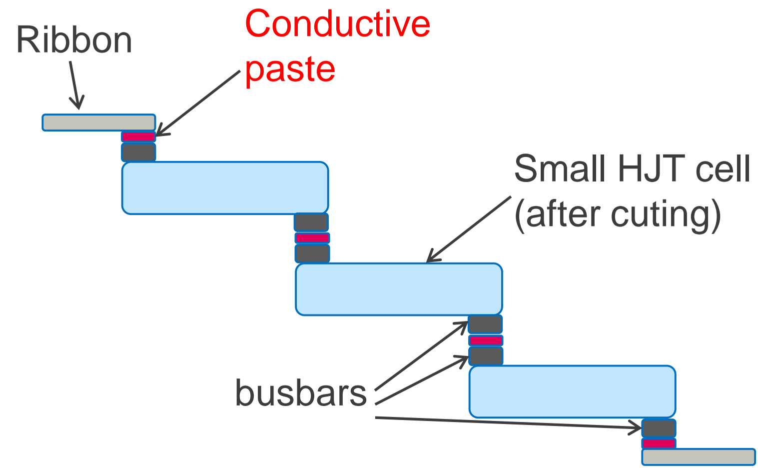


CTM losses	Eff da (%)	Power (%)
	+1.5%	-4.2%



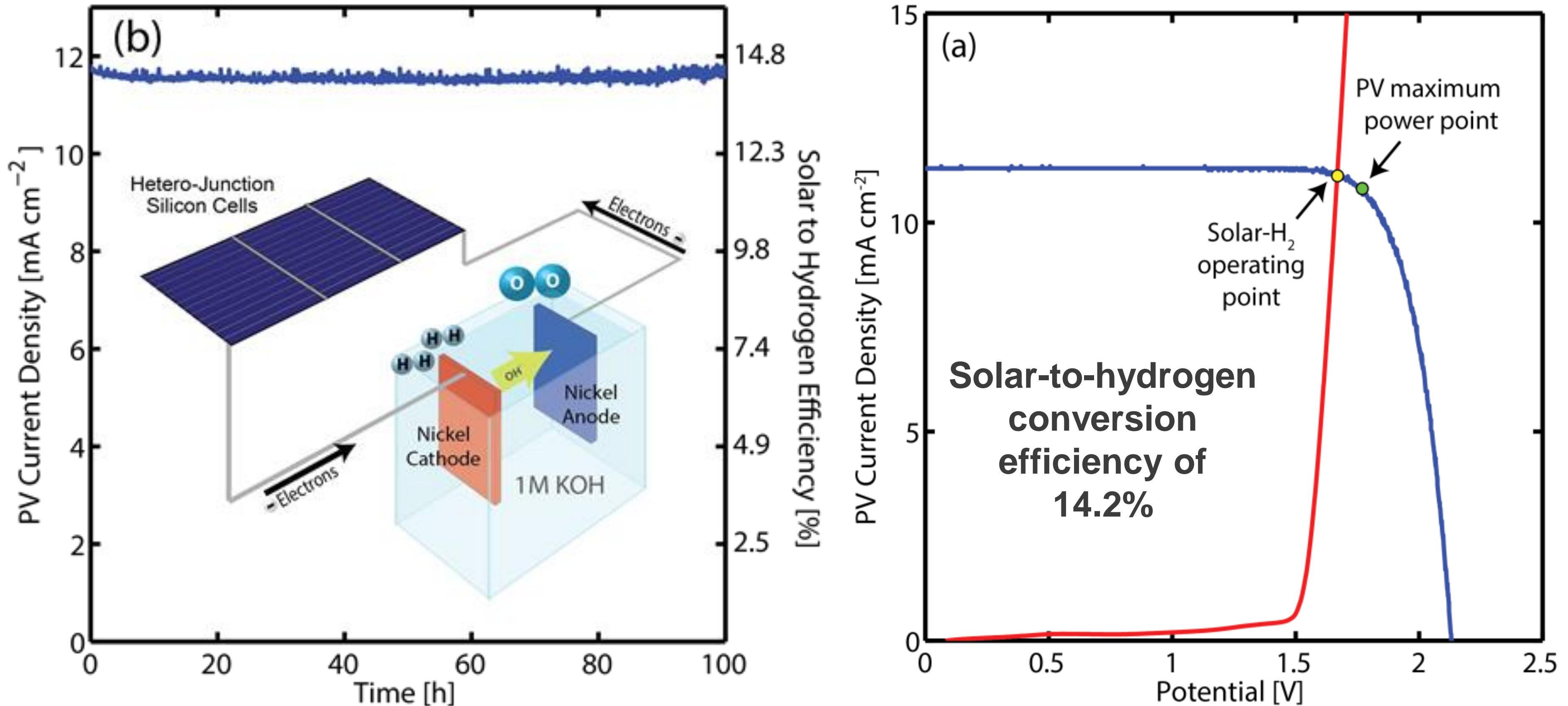
21% module efficiency

Pass 400TC



Cogenra-SunPower, SunEdison, SolarCity, GCL

Solar Water Splitting

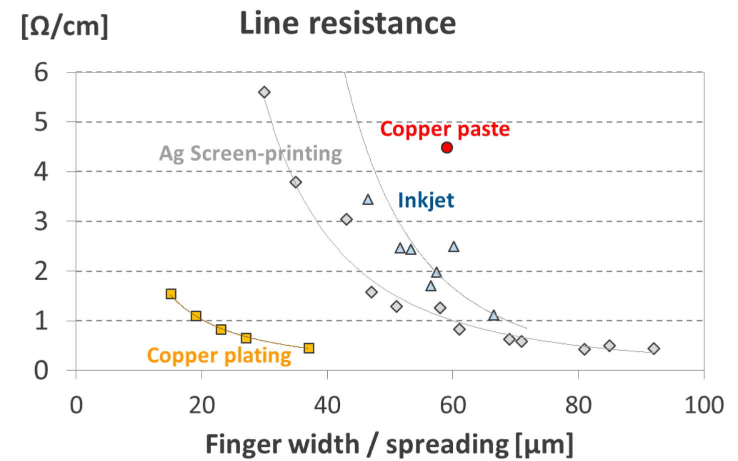


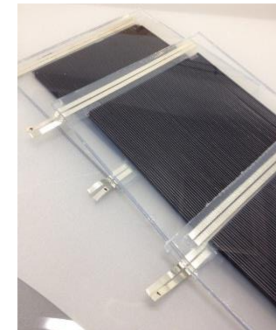
Highest efficiency in the world for solar water splitting based on Si PV & earth-abundant components

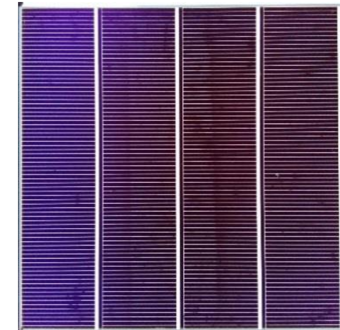
[1] J.-W. Schüttauf, JECS 163 (10) F1177-F1181 (2016).

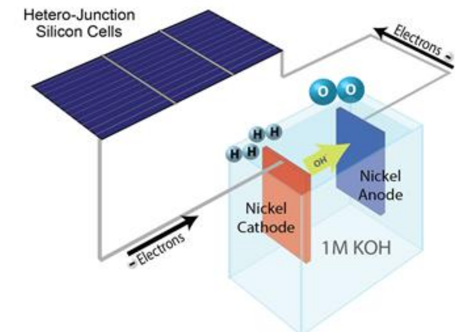
Conclusions

- **CSEM metallization platform**
  - Copper plating
  - Silver screen-printing
  - Silver inkjet printing
- **CTM gain** for metallization shadowing
- **SmartWire** reduces metallization cost and increases **module efficiency**
- **Indium-free SmartWire** for further cost reduction
- Module **without cell metallization**
- Module **without ribbon or wire interconnection**
- **World record** for solar water splitting based on Si PV & earth-abundant components









Acknowledgments

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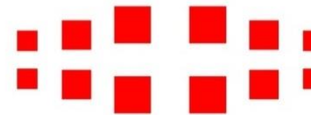
- Swiss Commission for Technology and Innovation with funding of the SmartWire and of DEFIA project
- Swiss Federal Office of Energy with funding of the Swiss Inno HJT project
- Choshu Industry Co, for cell precursors
- PVF-Vertriebs for the screen manufacturing and funding
- All co-authors for the work



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MEYER BURGER

Thank you for your attention

SolarPower Europe Prize 2016

antonin.faes@csem.ch