
1984•2014 YEARS 30

# Plating on Thin Conductive Oxides for Silicon Heterojunction Solar Cells

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**5th Workshop on Metallization of Crystalline Silicon Solar Cells, Constance, Germany, October 20th 2014**

# Outlines

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- Plating processes
  - Plating on Cu seed layer
  - Direct NiCu
  - Pretreatment + NiCu
- Contact resistance comparison on ITO and IWO
- Adhesion
- Material cost considerations
- Conclusions

# Reference lab process with Cu seed layer

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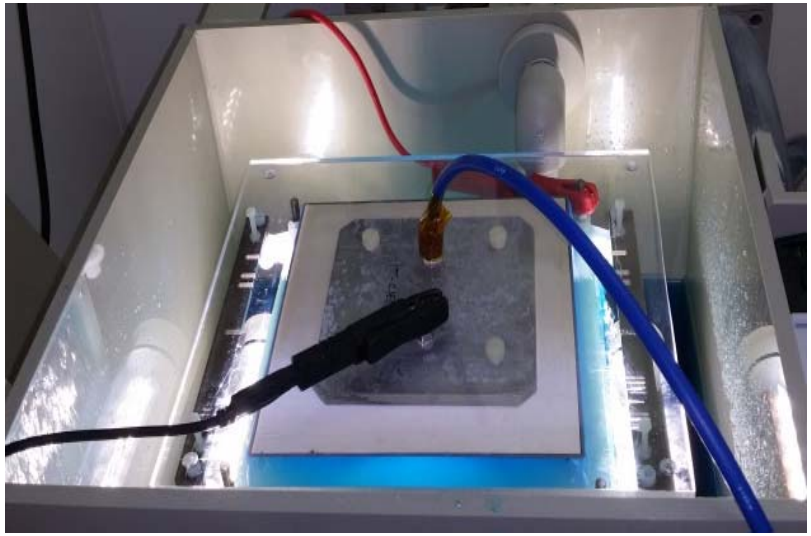
| Reference lab process |
|---|
| RS: sputtered Ag, ~200 nm |
| Annealing |
| **FS: Cu evaporated, ~200 nm** |
| Negative photoresist, exposure and development |
| Activation & copper plating |
| Resist removal |
| **Etch-back of Cu seed** |
| (Immersion Ag ~200 nm) |



Depicted: light induced plating without a seed layer

- Forward bias plating (also called field-induced plating) on front emitter cells with contacting on the rear side
- Substrates: 156 mm x 156 mm are provided by our project partners (with ITO or IWO)

# Reference lab process with Cu seed layer

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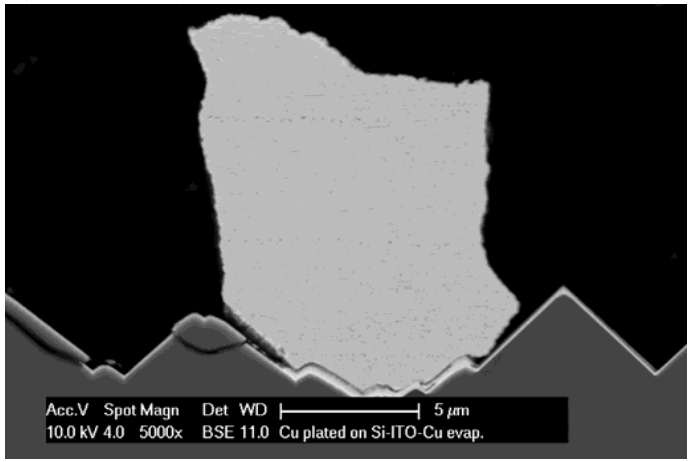
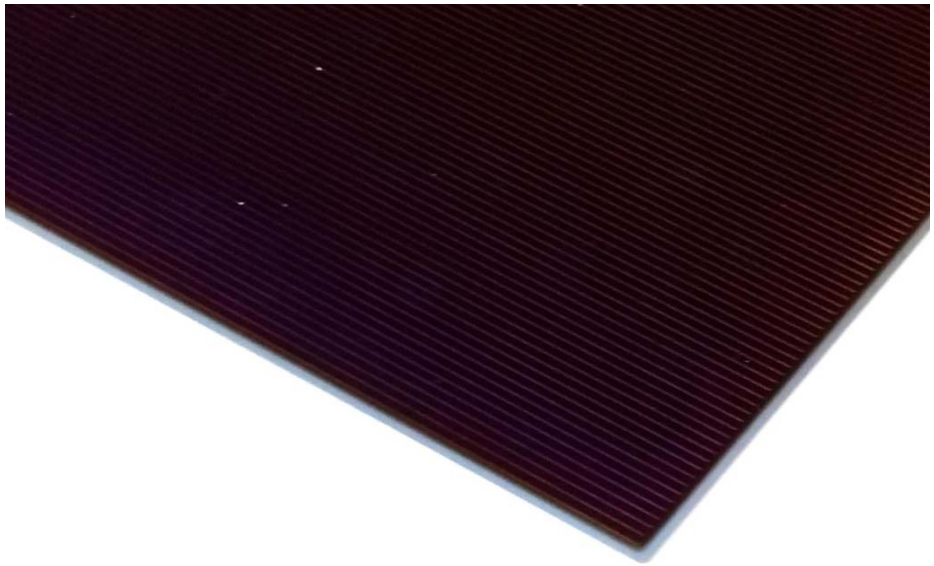
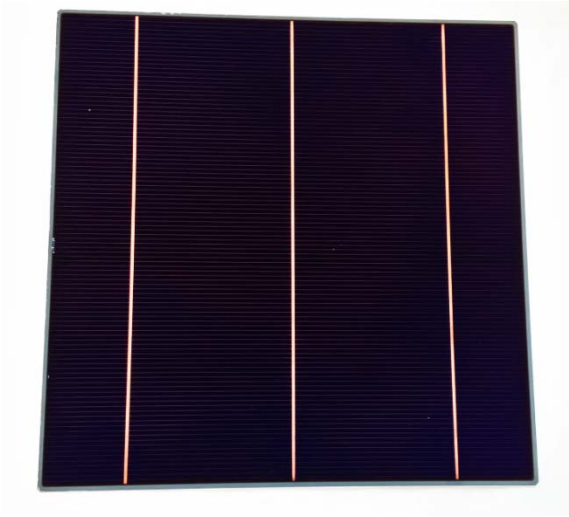
- Intrinsic weakness: underetching of the seed layer underneath the fingers
- Good results on 156 mm x 156 mm cells obtained with 30 µm openings using a negative resist and simple laboratory equipment
- Good adhesion

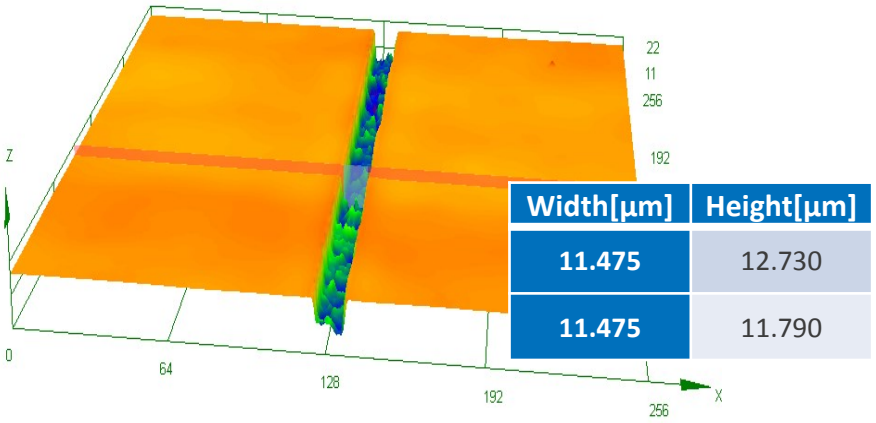


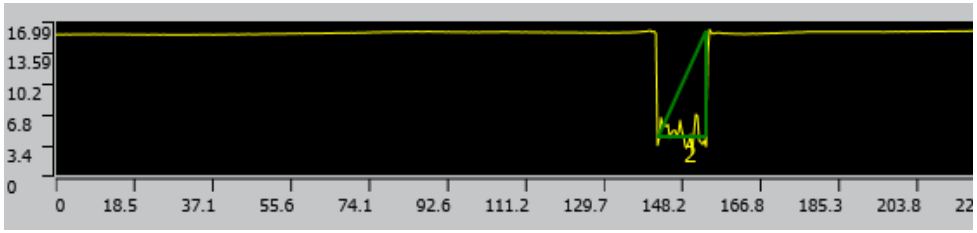


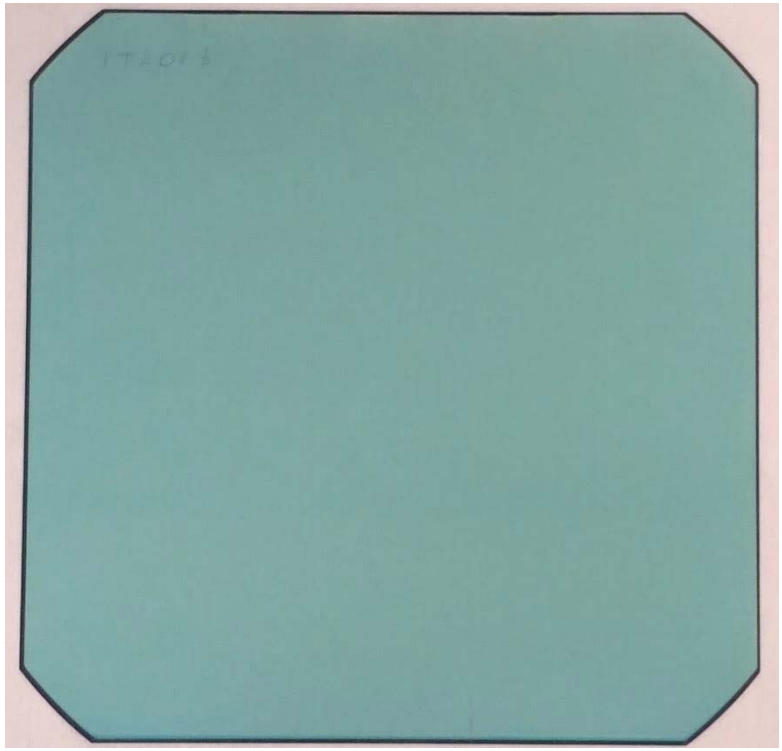
# Patterning

- The photoresist is applied by dip coating
- Uniform resist thickness over the entire wafer is achievable using an equipment with a precise control of the withdrawing speed.
- UV exposure with collimated light




| Width[µm] | Height[µm] |
|---|---|
| 11.475 | 12.730 |
| 11.475 | 11.790 |



Resist on the rear side, on sputtered silver layer

# Development and plating

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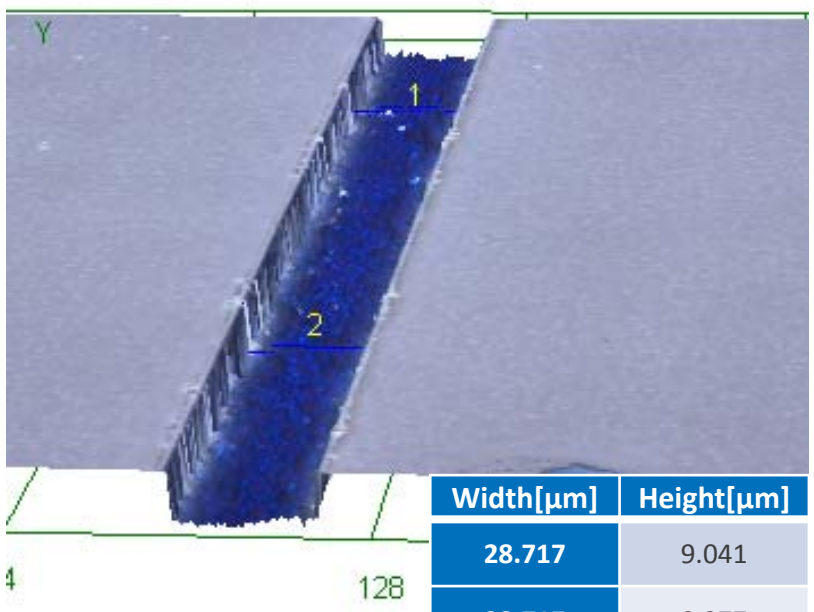
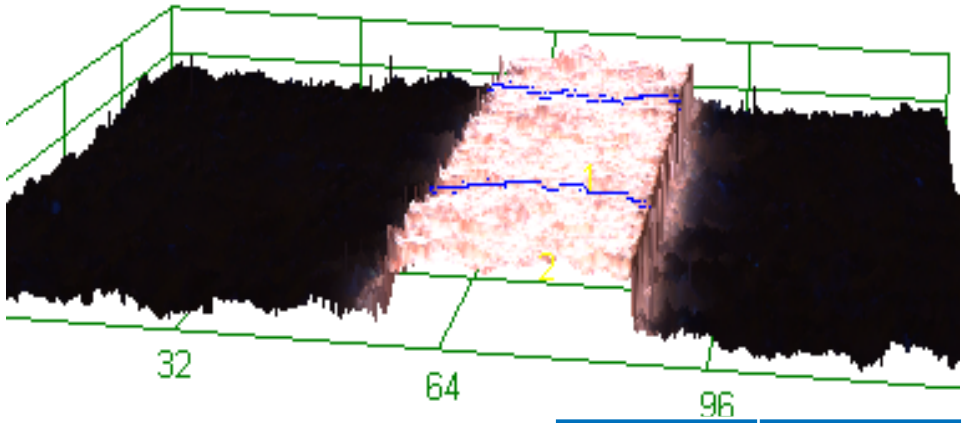
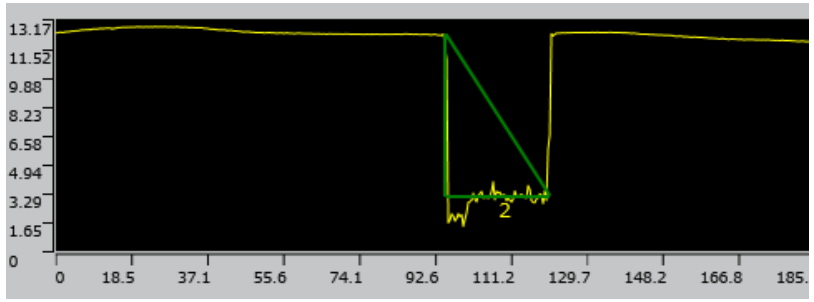
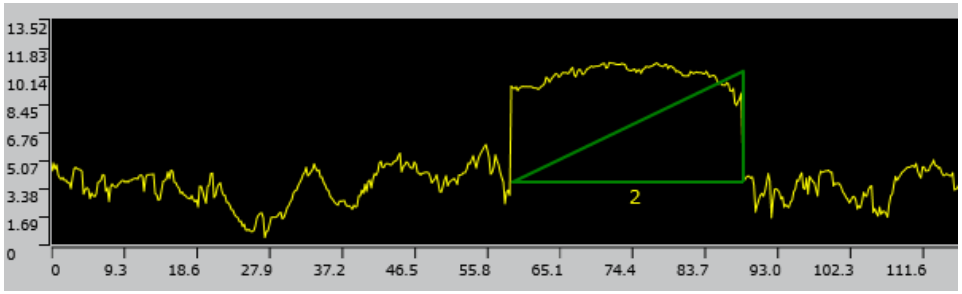



| Width[µm] | Height[µm] |
|---|---|
| 28.717 | 9.041 |
| 28.717 | 9.277 |




| Width[µm] | Height[µm] |
|---|---|
| 29.858 | 6.659 |
| 29.688 | 6.659 |



# Direct NiCu plating

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| Reference lab process | Direct NiCu plating |
|---|---|
| RS: sputtered Ag, ~200 nm | RS: sputtered Ag, ~200 nm |
| Annealing | Annealing |
| **FS: Cu evaporated, ~200 nm** | |
| Negative photoresist, exposure and development | Negative photoresist, exposure and development |
| Activation & copper plating | Nickel & copper plating |
| Resist removal | Resist removal |
| **Etch-back of Cu seed** | |
| (Immersion Ag ~200 nm) | (Immersion Ag ~200 nm) |

- Enables light induced plating on rear-emitter cells with contacting on the rear side
- Adhesion of plated fingers sufficient on ITO [1]
- Non-adherent fingers on IWO (using the available plating baths)

[1] P. Papet et al., Proc. of 28th EU PVSEC, Paris, 2013

# Direct NiCu plating with pretreatment

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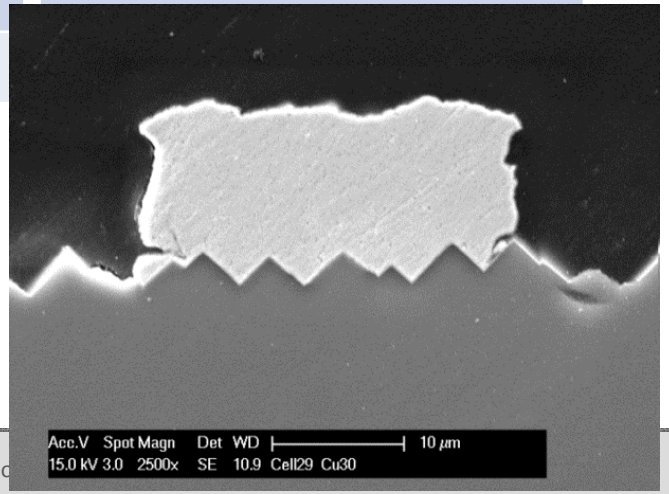
| Reference process with Cu seed | Direct NiCu plating | Pretreatment + NiCu plating |
|---|---|---|
| RS: sputtered Ag, ~200 nm | RS: sputtered Ag, ~200 nm | RS: sputtered Ag, ~200 nm |
| Annealing | Annealing | Annealing |
| **FS: Cu evaporated, ~200 nm** | | |
| Negative photoresist, exposure and development | Negative photoresist, exposure and development | Negative photoresist, exposure and development |
| Activation & copper plating | Nickel & copper plating | Pretreatment, nickel & copper plating |
| Resist removal | Resist removal | Resist removal |
| **Etch-back of Cu seed** | | |
| (Immersion Ag ~200 nm) | (Immersion Ag ~200 nm) | |

- Light induced plating of rear emitter cells possible
- Good adhesion on IWO (so far not tested on ITO)
- Process still under development



# Also possible …

| Width[µm] | Height[µm] |
|---|---|
| 5.421 | 8.387 |
| 5.591 | 7.665 |

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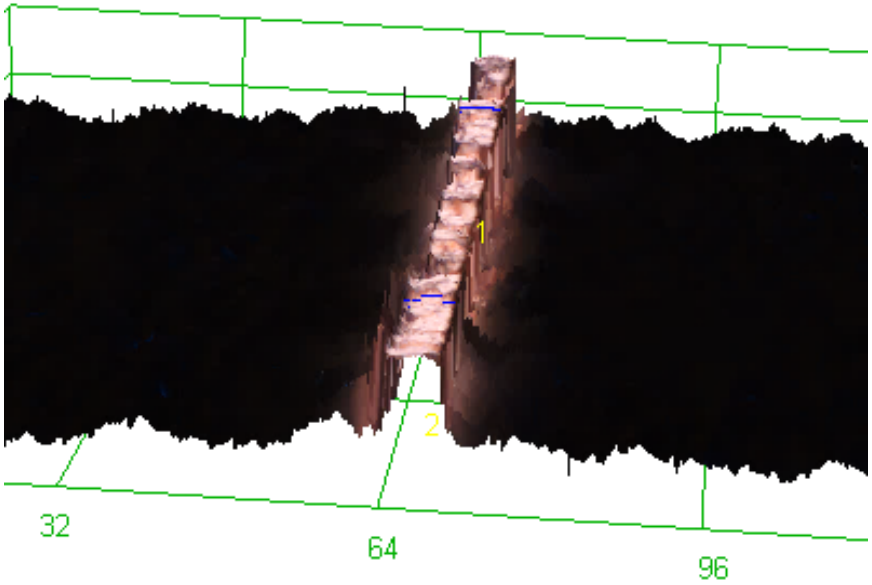
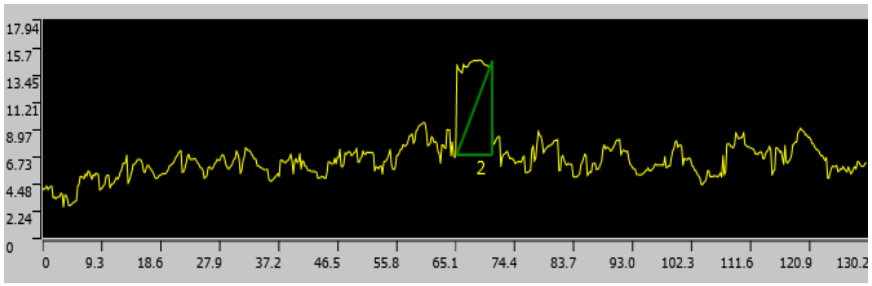
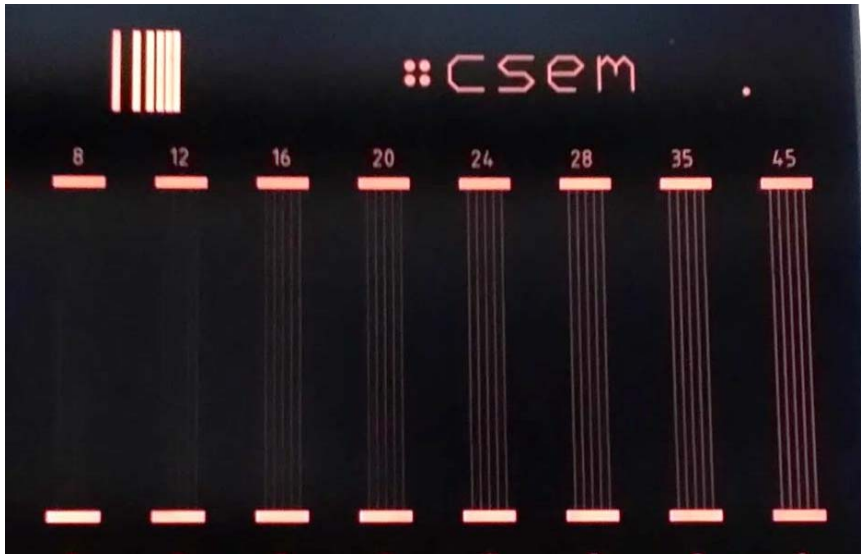



- Substrate: rear emitter cell with IWO
- Negative photoresist
- Pretreatment and LIP-NiCu
- Line withstands the tape test



# Contact resistance

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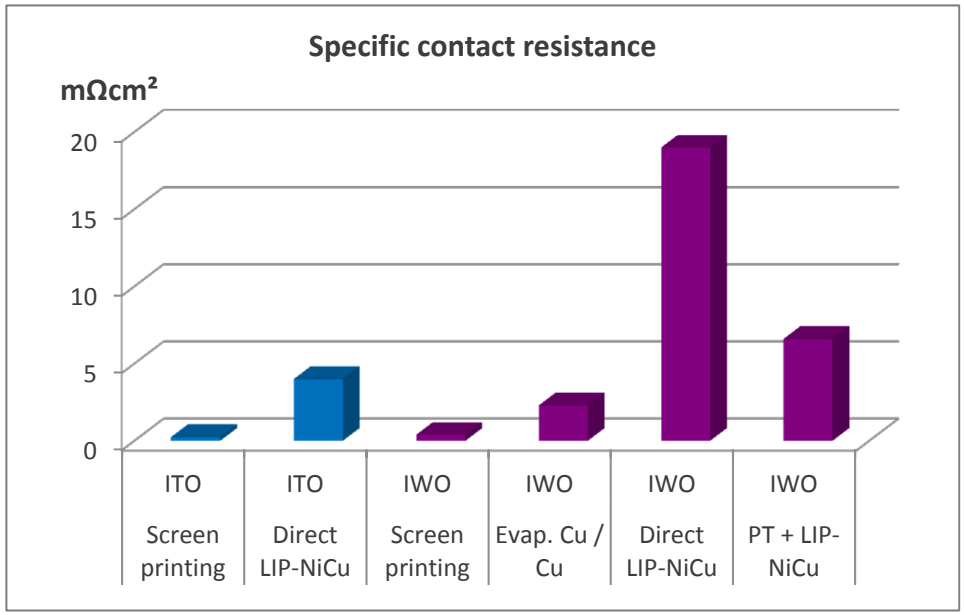


- Lowest contact resistance with screen printed metallization
- Poor adhesion on cells with direct LIP-NiCu on IWO

- Values reported in literature may vary by more than one order of magnitude for the same TCO and the same metallization, which is certainly a concequence of diffent TCO deposition parameters and different silver pastes used.
  E.g. for screen printed Ag paste on ITO following values have been reported: 2 mΩcm² [1] and 0.01 mΩcm² [2]
- Also for NiCu direct plating on ITO a very low value of 0.1 mΩcm² has been reported [2]


[1] L. Barraud et al., Solar Energy Materials and Solar Cells115 (2013) 151 – 156
[2] J. Geissbühler et al., IEEE J. Photovoltaics, vol. 4, no. 4, July 2014

# Adhesion / peel test after soldering

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- Standard soldering profile with peak temperature 250°C, ribbons with SnAg coating
- Very poor adhesion on all samples.
  Only on a cell processed with pretreatment and NiCu LIP- plating peel forces between 0.3 – 0.5 N/mm could be measured
- **But**

  **SmartWire® modules with directly LIP-plated NiCu on ITO are stable and do not show any adhesion issues.**
  **TCT 200: -1.1%, DH 1100h: -0.4%, DH 3000h: -3.1% [1]**

- Soldering tests also with low meling point alloy will be carried out
- For standard BB connection the adhesion has to be substantially improved

[1] P. Papet et al., Metallization Workshop, Constance, 2013

# Cell results

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- Busbar-less cells with IWO
  - Layout 105 finger, 30 µm opening
  - Plated copper thickness ~7 µm

- Front-emitter cell with Cu seed and Cu plating

| Cell | Eff. [%] | Voc [mV] | Jsc [mA/cm2] | FF [%] |
|---|---|---|---|---|
| IWO FE SP reference (met. area 3.0%) * | 21.9 | 734.2 | 37.5 | 79.7 |
| IWO FE evap.Cu/Cu (met. area 2.1%) | 21.9 | 733.3 | 38.3 | 77.8 |

- Rear-emitter cell with pretreatment and NiCu plating

| Cell | Eff. [%] | Voc [mV] | Jsc [mA/cm2] | FF [%] |
|---|---|---|---|---|
| IWO RE SP reference (met. area 3.0%) * | 22.6 | 735.2 | 38.7 | 79.4 |
| IWO RE PT/LIP-NiCu (met. area 2.1%) | 22.8 | 733.6 | 39.2 | 79.2 |

Measured with GridTouch®

* The reference cells with screen printed metallization has been provided by our project partner

# Cell results

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- Consistently higher Jsc values have been achieved already with 30 µm wide plated fingers but at always lower FF resulting in approximately the same efficiency as screen printed cells (fine lines).
  According to simulations contact resistance is the limiting factor for the efficiency while reducing the finger width.
- Similar trends has been observed on ITO with direct NiCu plating [1]
- The slightly lower Voc is attributed to additional manual handling during processing for plating

[1] P. Papet et al., Proc. of 28th EU PVSEC, Paris, 2013

# Material cost considerations for bifacial cells

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| Screen printing | Plating with a seed layer |
|---|---|
| Texturing and Cleaning | Texturing and Cleaning |
| PECVD a-Si layers | PECVD a-Si layers |
| PVD Thin Conductive Oxide | PVD Thin Conductive Oxide |
| Screen-printing front | Curing |
| Drying | Seed layer deposition |
| Screen-printing rear | Patterning (resist application and exposure) |
| Curing | Resist development, plating, resist and seed layer removal, immersion silver |

- The cost of photoresist is approximately 4.5 €ct/wafer for a low-cost resist with moderate resolution (20 µm line/space) at 7 µm thickness on both sides
- The chemistry and material cost for wet processes is approximately 0.5 €ct/wafer
- This is already more than the silver paste cost for bifacial busbar-less cell

- Ag paste consumption for bifacial cells with busbars is at minimum 250 mg/wafer, the Ag cost is accordingly higher than 11 €ct/wafer (Ag price: 440 Euro/kg [1])
- Ag paste consumption for bifacial busbar-less cells is currently at 100 mg [2], corresponding to 4.4 €ct/wafer. The overall cost per Wp for SmartWire® modules is lower than for standard modules [3]

[1] finanzen.net, 17.10.2014.
[2] P. Papet et al., this Metallization Workshop
[3] P. Papet et al., Metallization Workshop, Constance, 2013

# Conclusions

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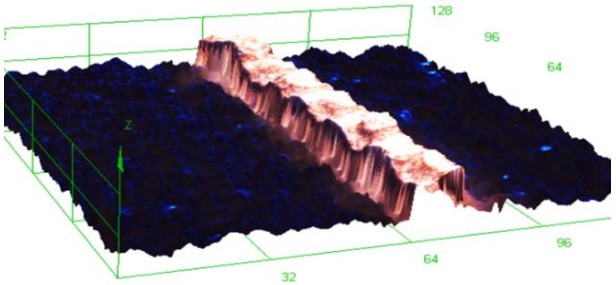
- Higher contact resistance and lower fill factor are measured for plated metallization compared to screen printing (using described processes) .
- Different contact resistance and adhesion on ITO and IWO
- Adhesion is very poor after soldering at standard Pb-free profile
- Cost reduction / process simplification is necessary in order to make plating competive for busbar-less cells for SmartWire® connection

- Future tasks at CSEM:
  - Evaluation of contact resistance for different TCOs and different plating processes
  - Improvement of adhesion
  - Patterning / cost reduction for a cost competitive plating process for busbar-less cells

# Thank you for your attention!

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