Aerosol-Printed Silicon Solar Cell Exceeding 20% Efficieny

Crystal-Clear-Workshop

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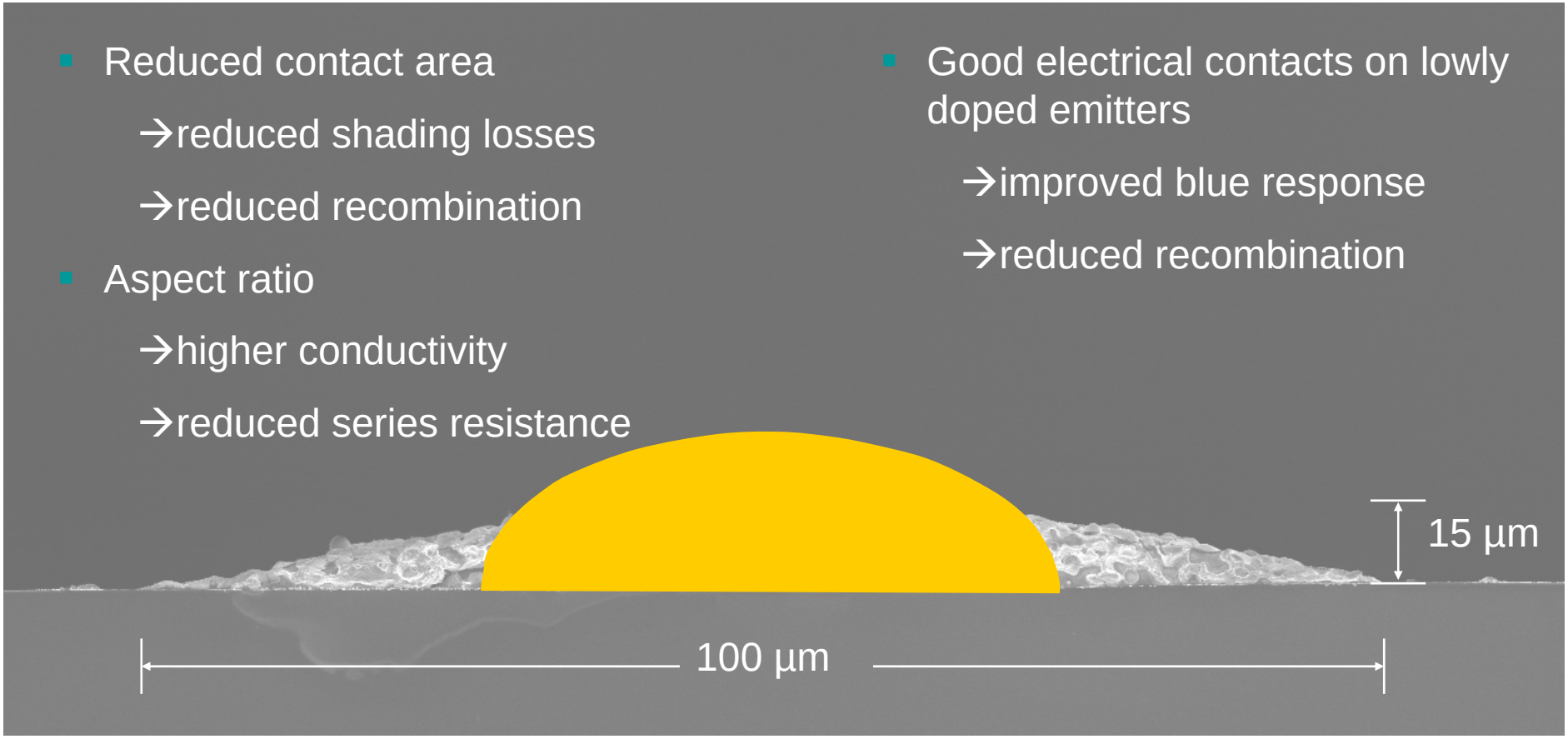
Fraunhofer Institut Solare Energiesysteme

Motivation, Screen print contact - “new”-contact

- Reduced contact area
  - →reduced shading losses
  - →reduced recombination
- Aspect ratio
  - →higher conductivity
  - →reduced series resistance
- Good electrical contacts on lowly doped emitters
  - →improved blue response
  - →reduced recombination



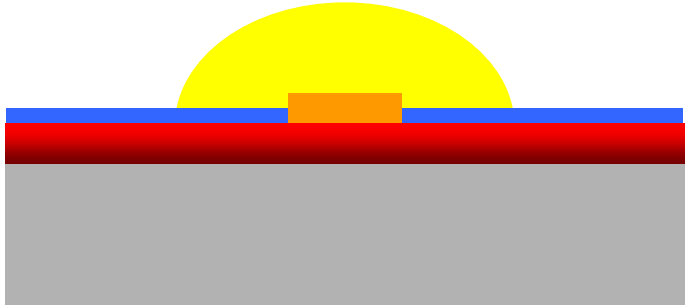
Content

- Seed layer concepts
- Aerosol print technique
- Ink preparation at Fraunhofer ISE
- Contact structure and formation
- Application: High efficiency solar cell

Two layer concept: Seed-layer and conductive-layer

Seed-layer

- Evaporation of contact metals trough a mask
- Direct laser scribing
- Electroless plating of contact metals
- Fine line screen print
- Aerosol-jet print / Ink-jet print

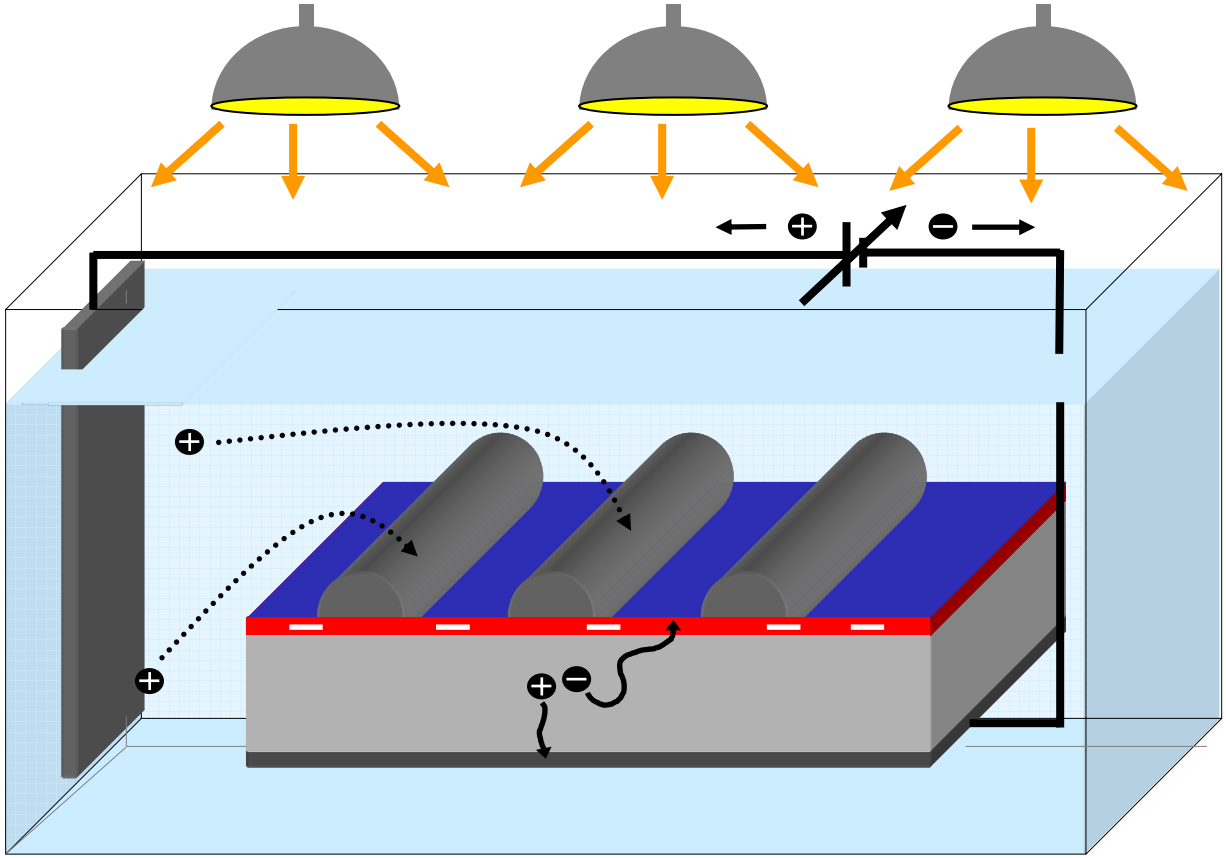


Conductive-layer

- Plating (light induced or electroless)
- Multiple printing of highly conductive materials

Light-induced plating

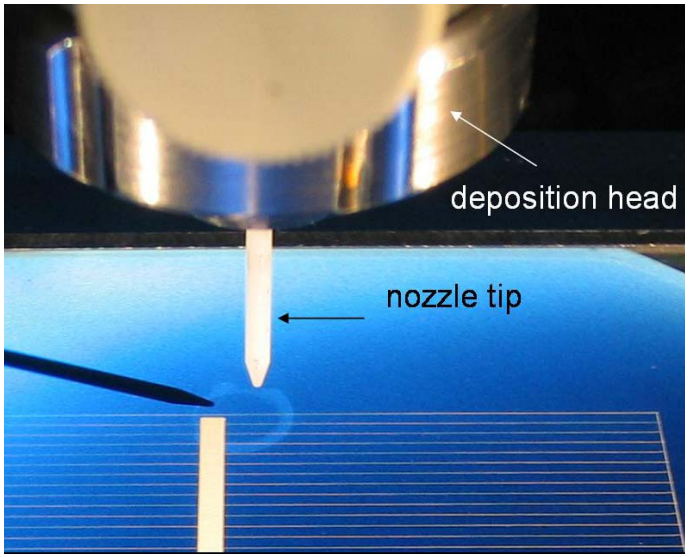
- Backside connected via external power supply to Silver anode
- Illumination induces negative potential on front side
- Positively charged Ag^{+}-ions are attracted by the illuminated front side and deposited along the seed layer

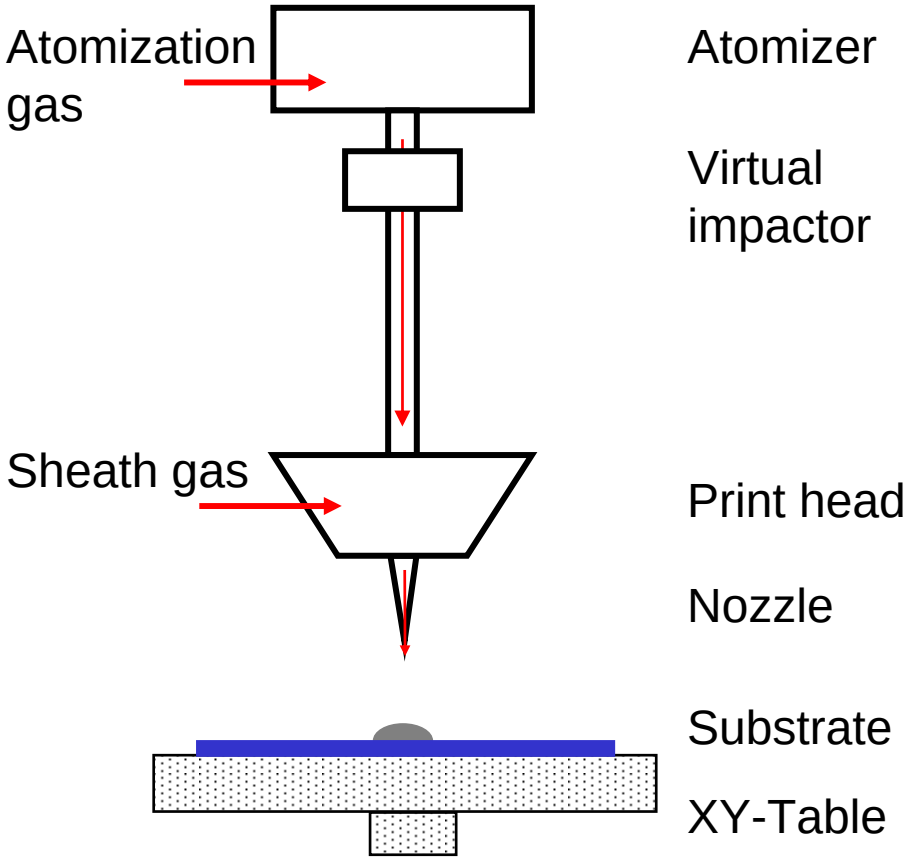


Light-induced-plating – industrial realization

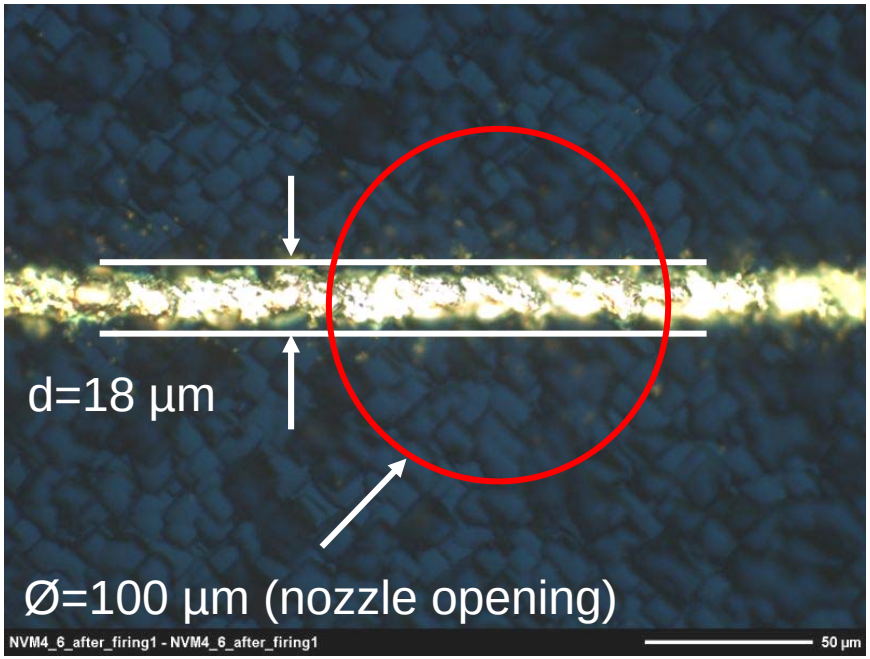
- Inline LIP at Fraunhofer ISE
- Two machines are available, for Ag and Cu

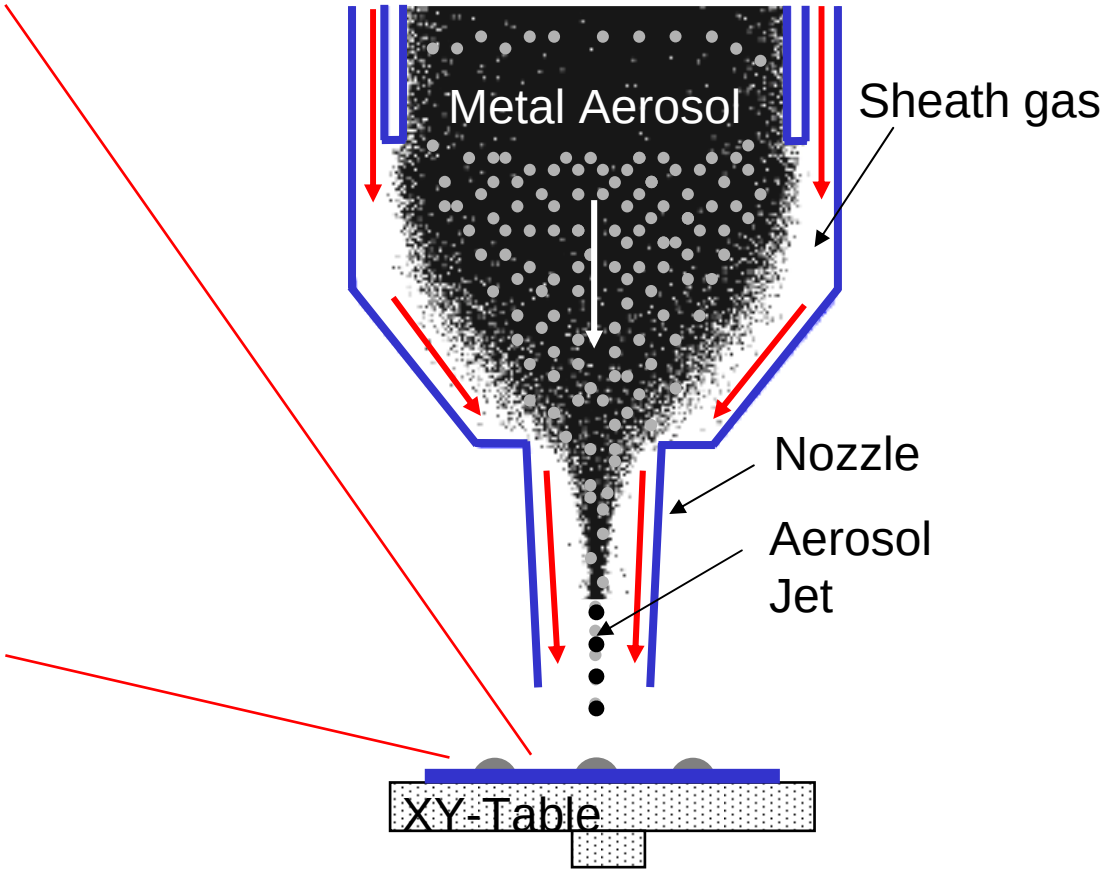
Schematic of an aerosol printer



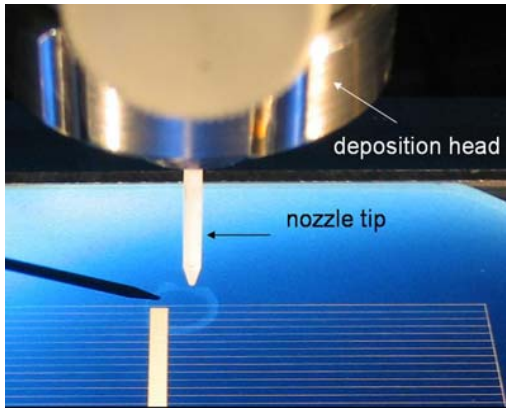


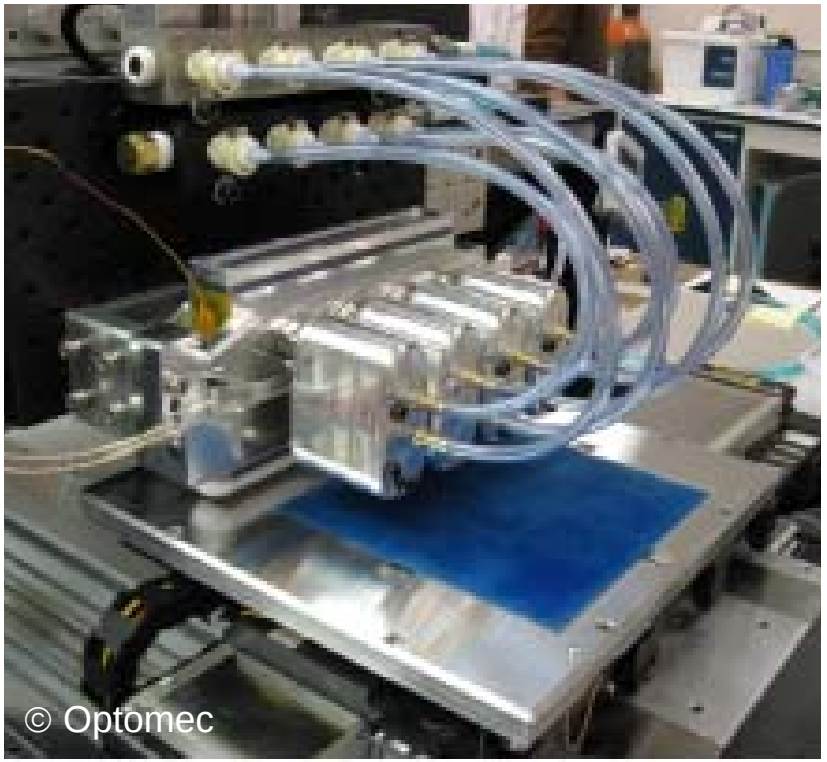
Aerosol print head





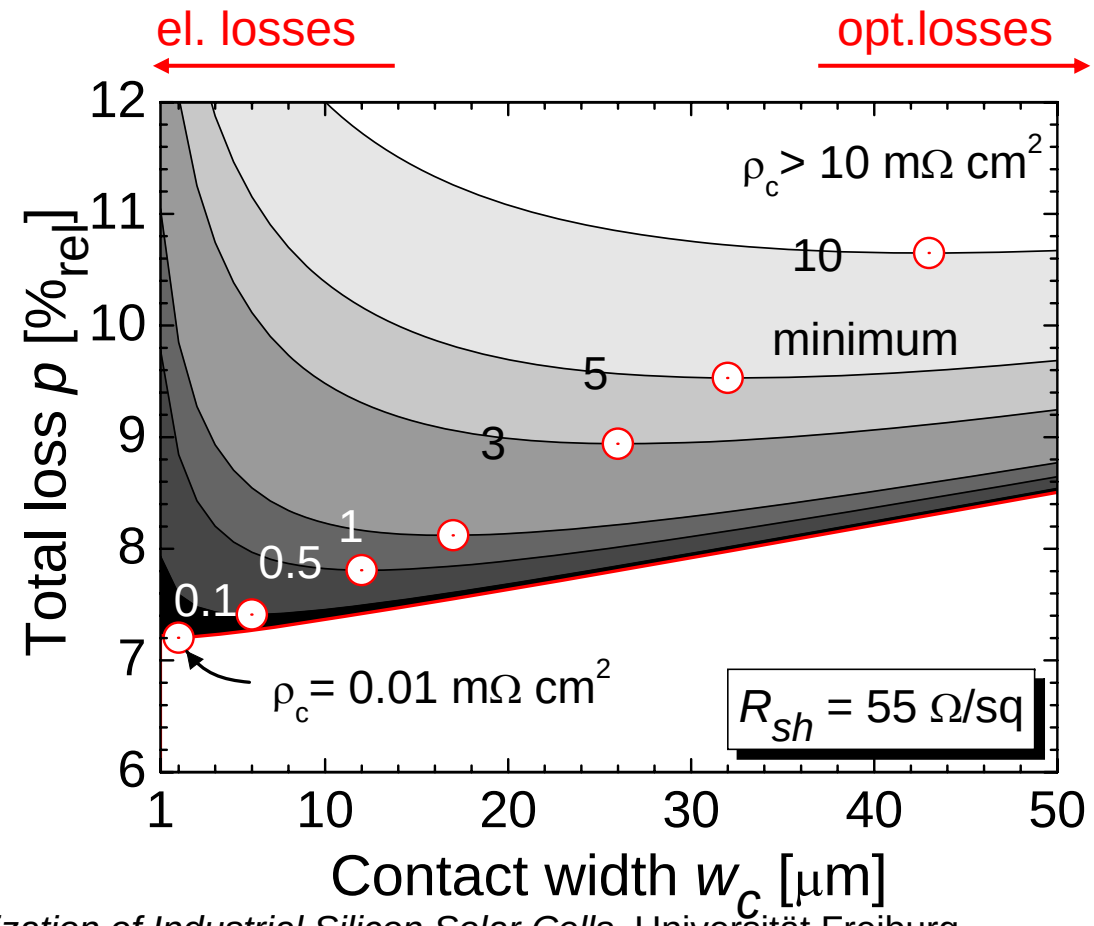
Printing systems





Simulation: optimized contact width

- Influence of optical losses
- Influence of electrical losses
- Dependent on contact resistivity



Mette A., *New Concepts for Front Side Metallization of Industrial Silicon Solar Cells,* Universität Freiburg

Functional ink materials

- Metal powder - Silver

⇒ Conductivity and contact

- Glass frit (Metal Oxides)

⇒ Contact formation and adhesion

- Organic vehicle system (Solvents, binder, dispersant agents, rheological additives…)

⇒ Adjusting the ink on the used printing system (Screen print, Aerosol print, Inkjet print…)

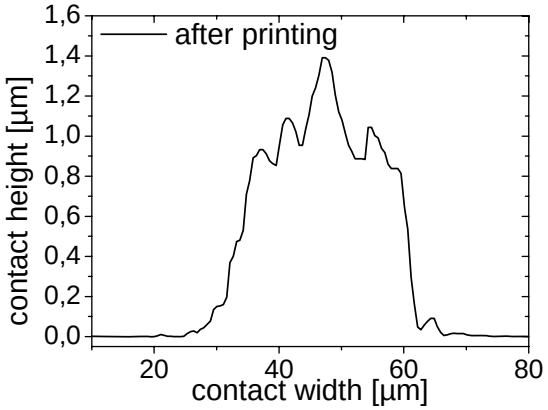
Ink - Preparation

Tools:

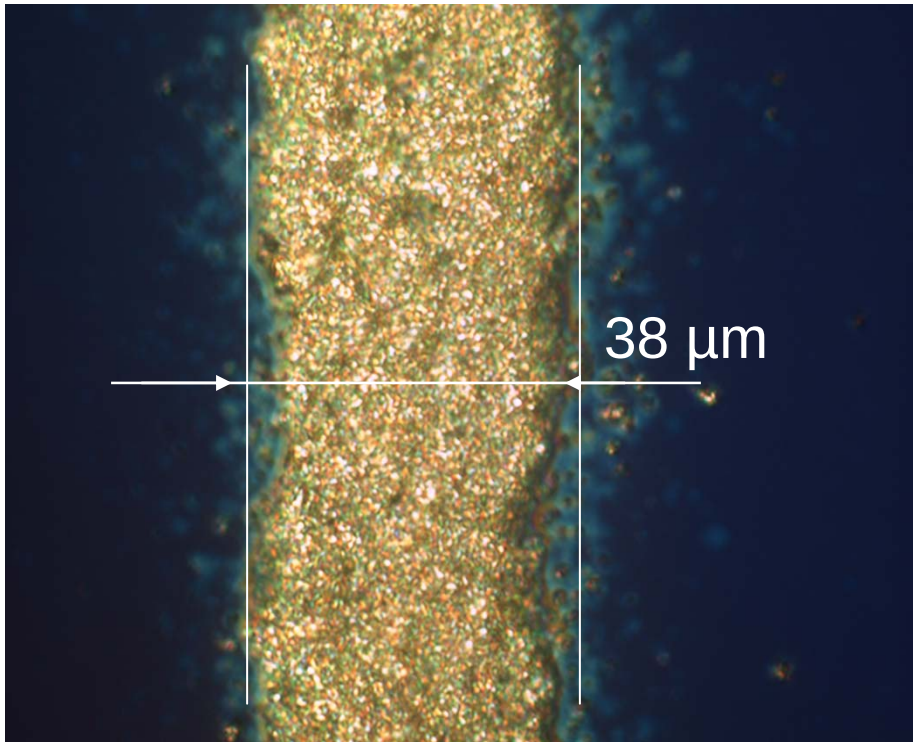
- Crushing
  - →Mortar
  - →Ball mill
- Mixing
  - →Agitatiors
  - →spatula and beaker
- Dispersing
  - →Ultra sonic finger/bath
  - →3 mill chair

www.d-firma.de/bilder/mischen.jpg

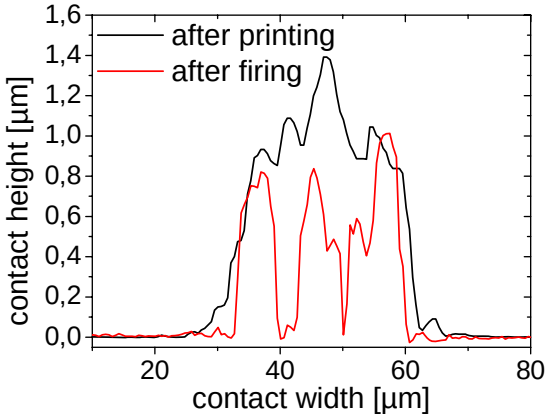
Aerosol contact after printing



- Single printed, dense line
- Line width <40 µm using a 200 µm nozzle
- Line height about 1-2 µm
- Height:width < 1/20

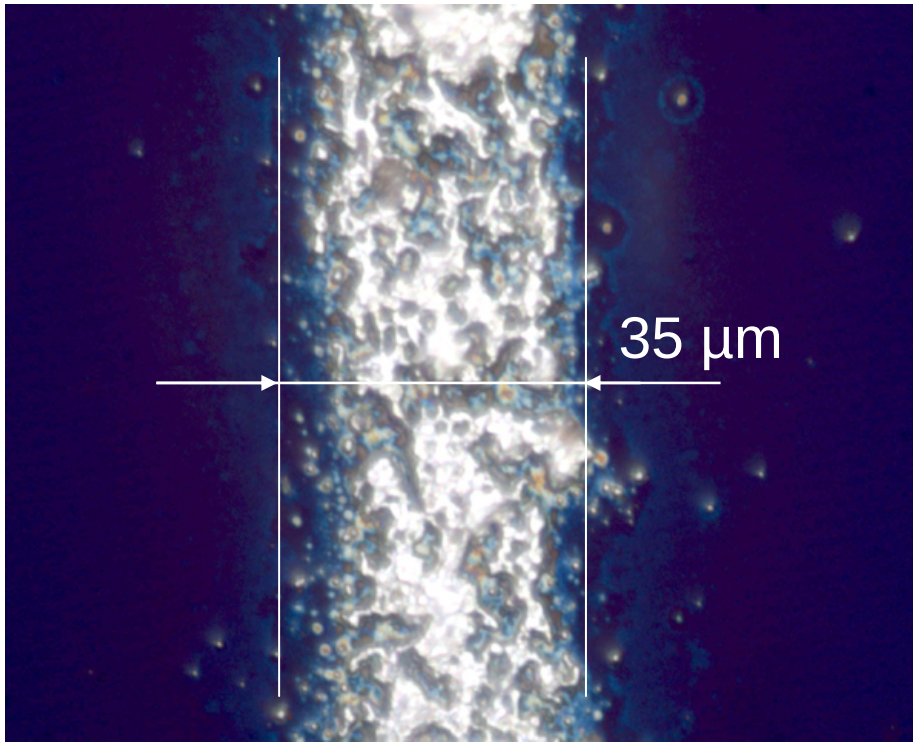


Aerosol contact after firing

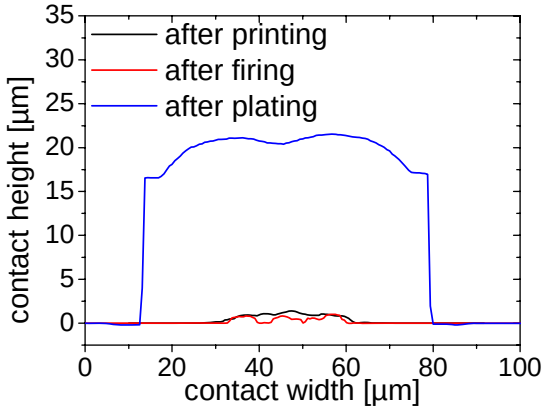


- Evaporation of solvent and binder
- Sintering of silver particles
- Reduced line conductivity

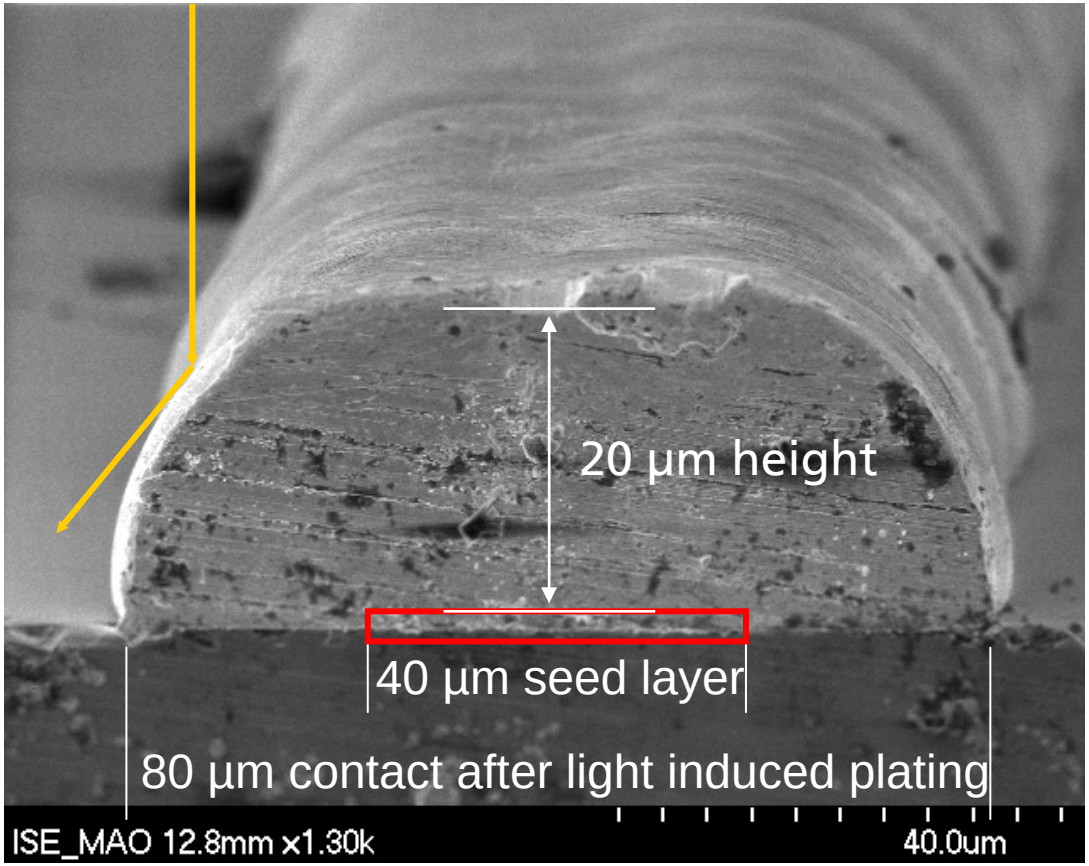
⇒ Light induced plating



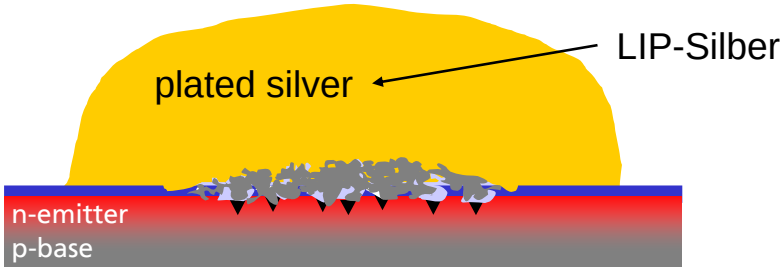
Aerosol contact after LIP

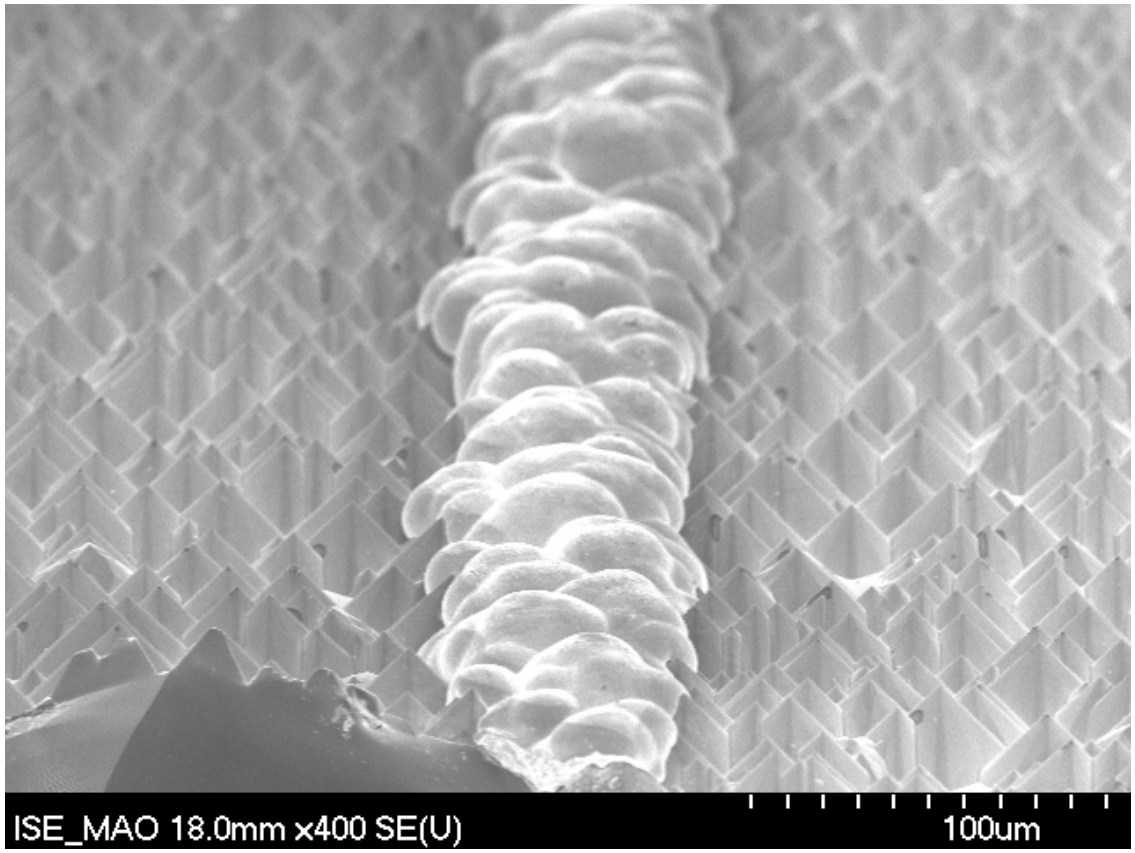


- Aspect ratio increases 1:4
- improved conductivity $\rho_f \sim 2\times10^{-8}\ \Omega m$
- Higher reflection (optical width about 70% of real contact width)



Reverse contact formation





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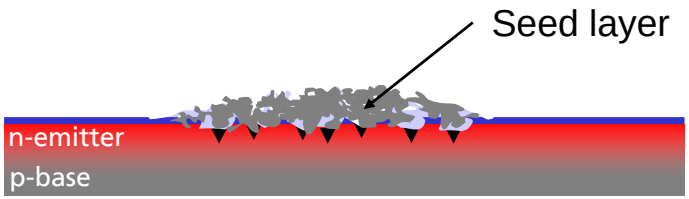
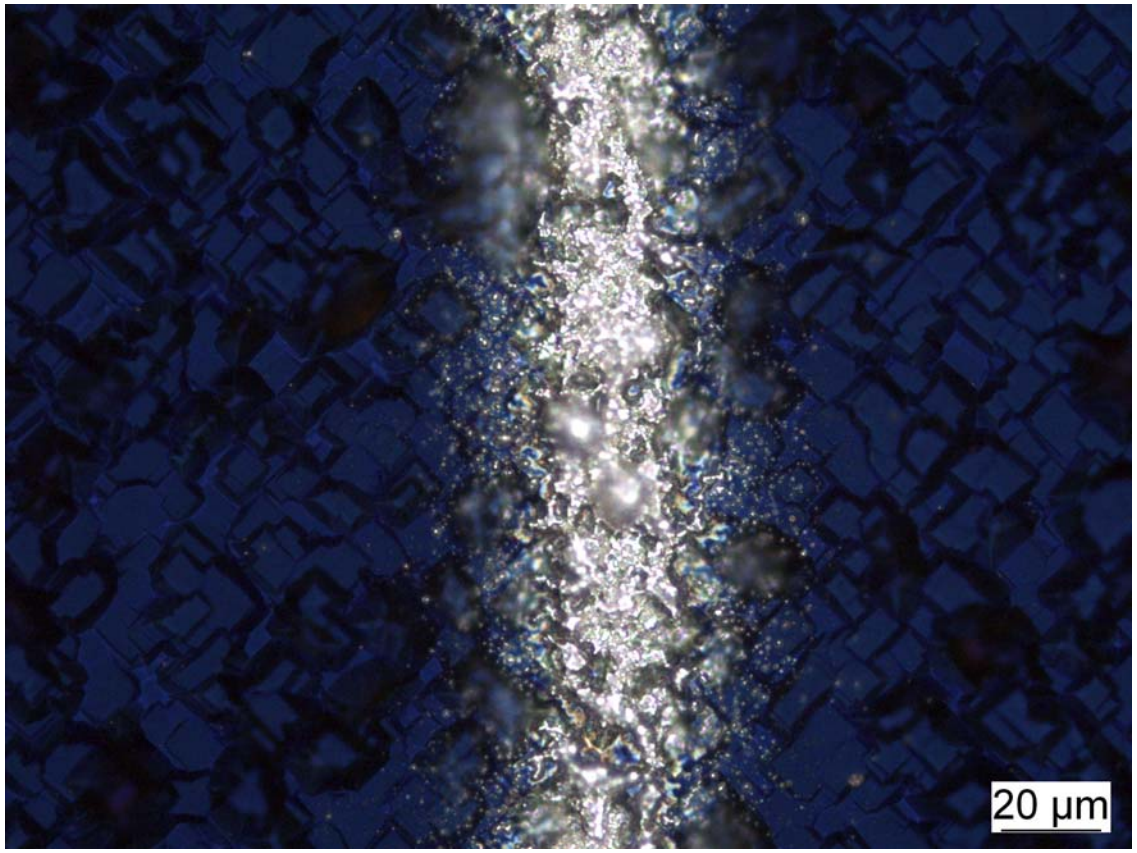


- LIP silver is removed by nitric acid



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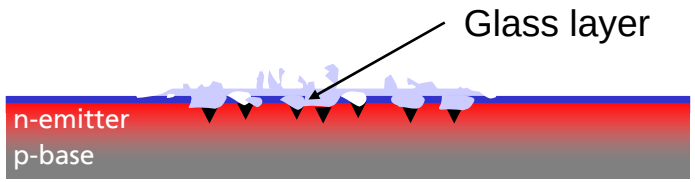
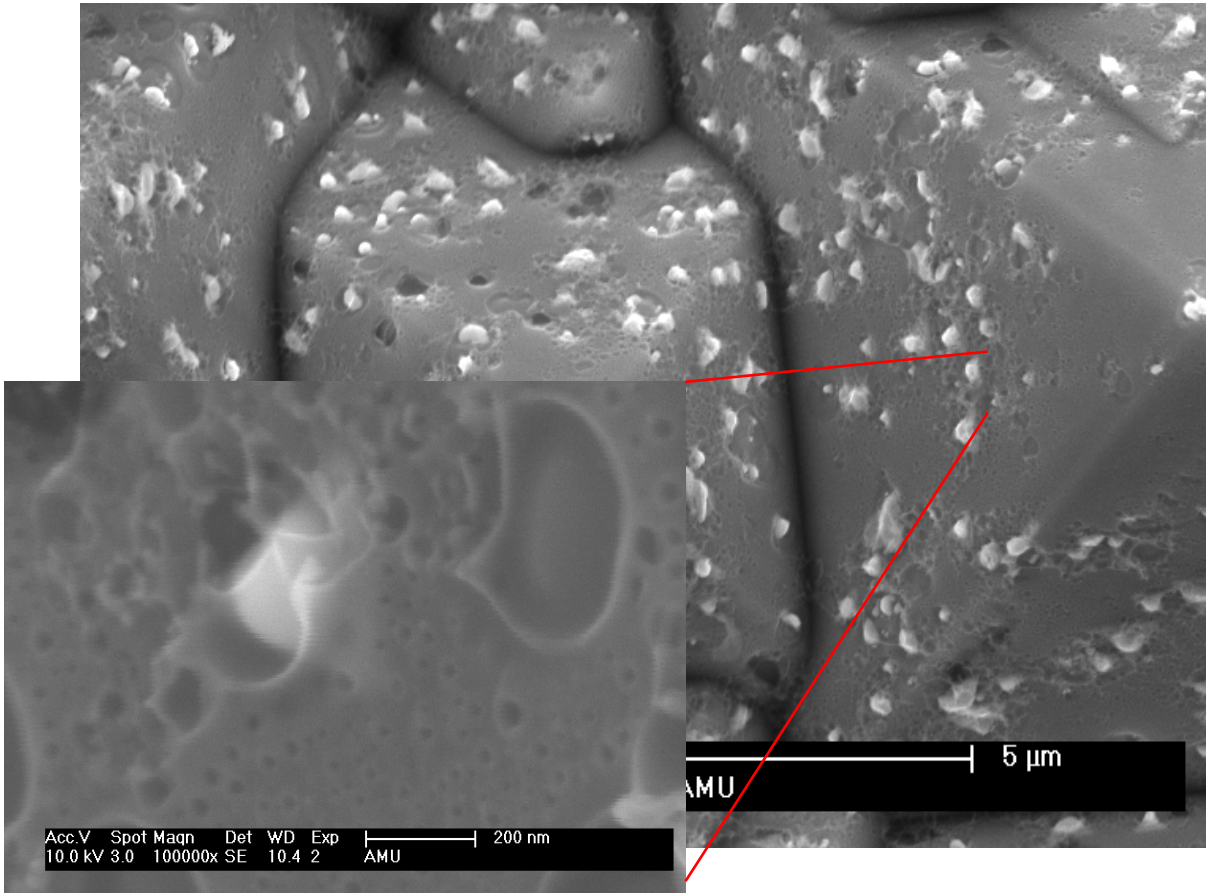
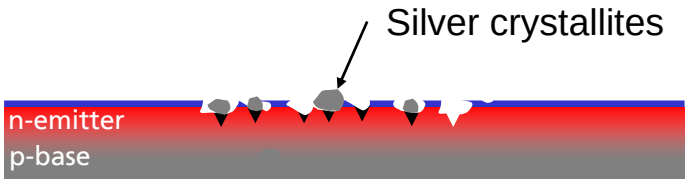


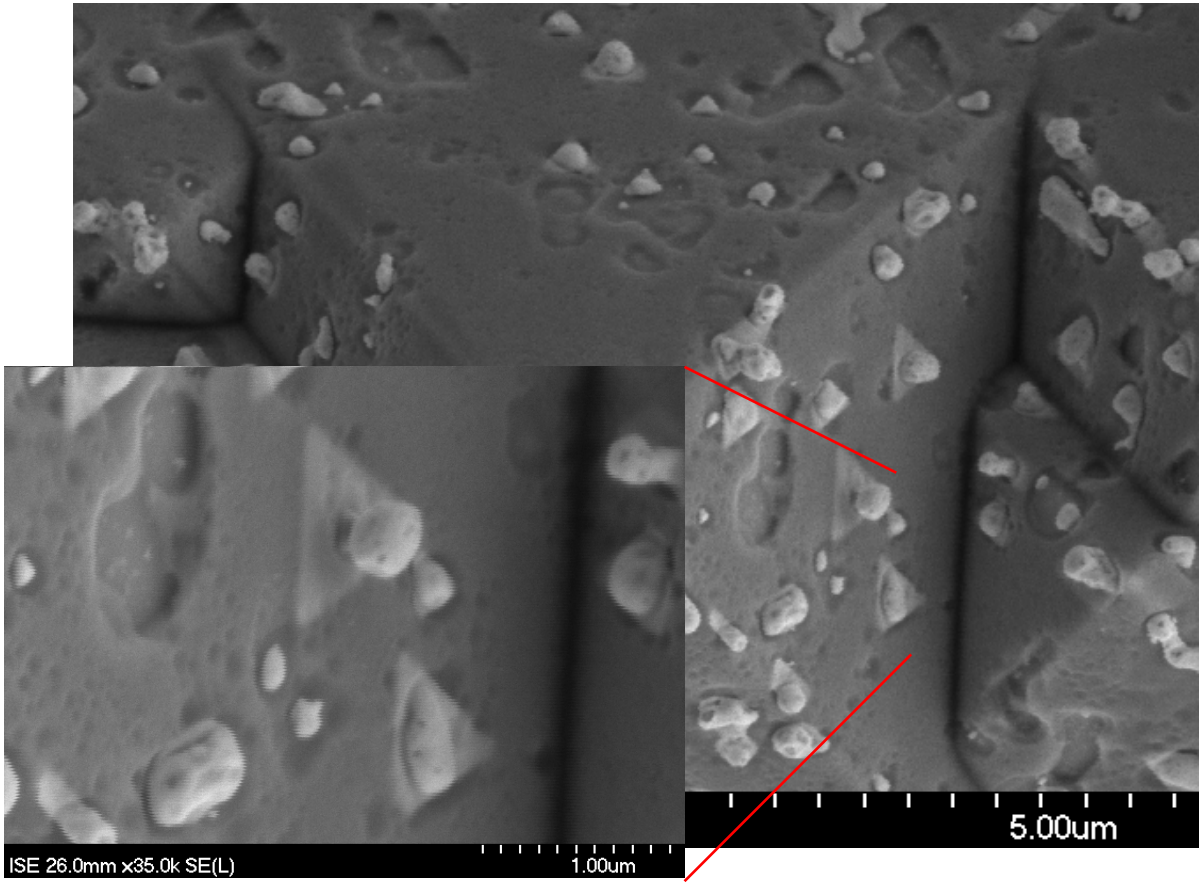
- LIP silver is removed by nitric acid
- Printed silver is removed



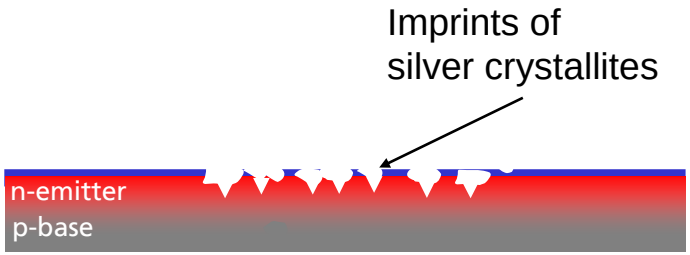
Reverse contact formation



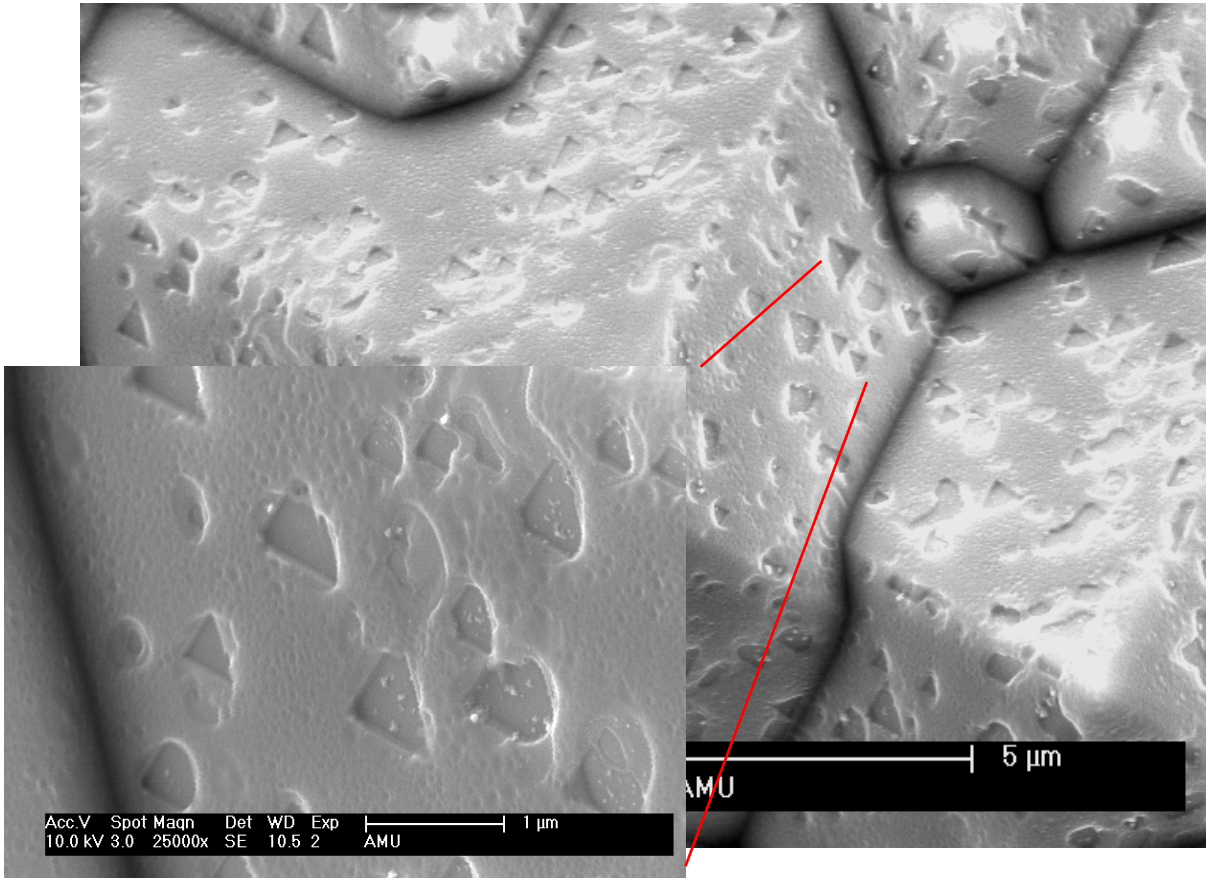
- LIP silver is removed by nitric acid
- Printed silver is removed
- HF dip to remove the glass layer



Reverse contact formation

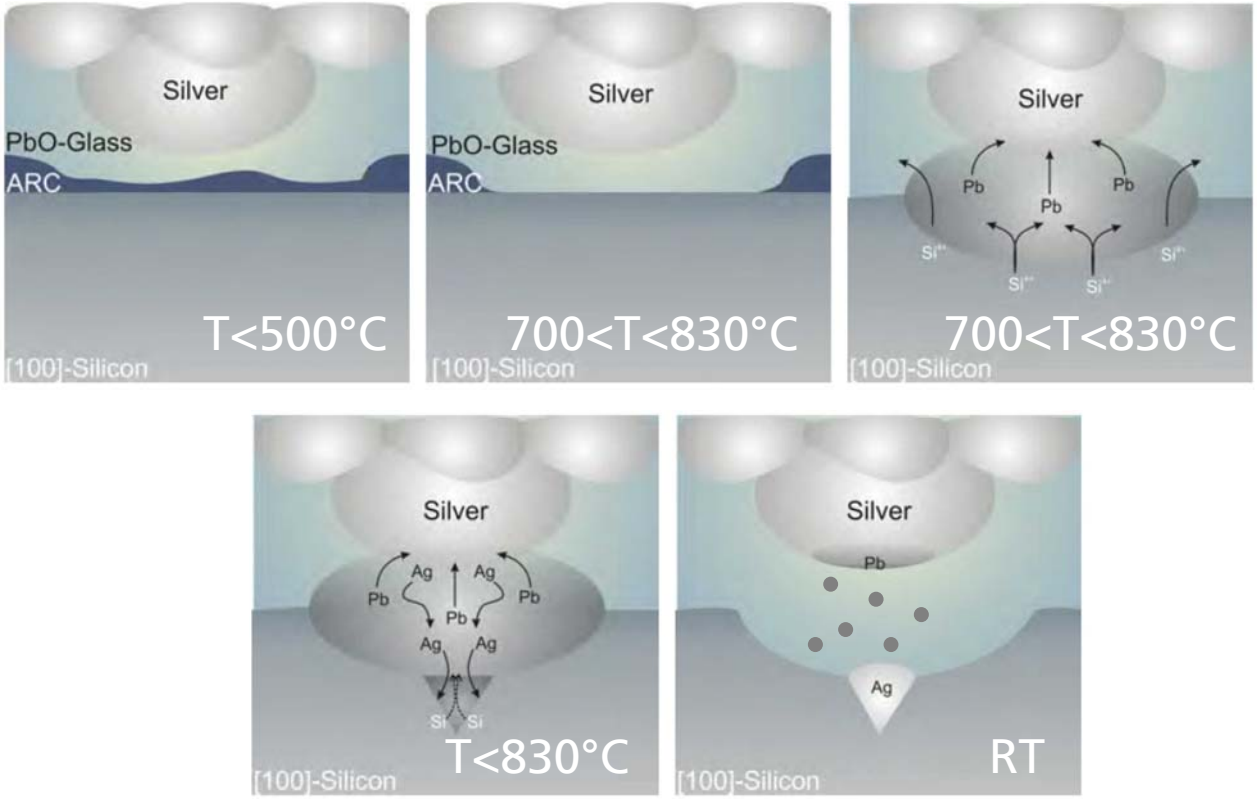


- LIP silver is removed by nitric acid
- Printed silver is removed
- HF dip to remove the glass layer
- Nitric acid to remove the silver crystallites



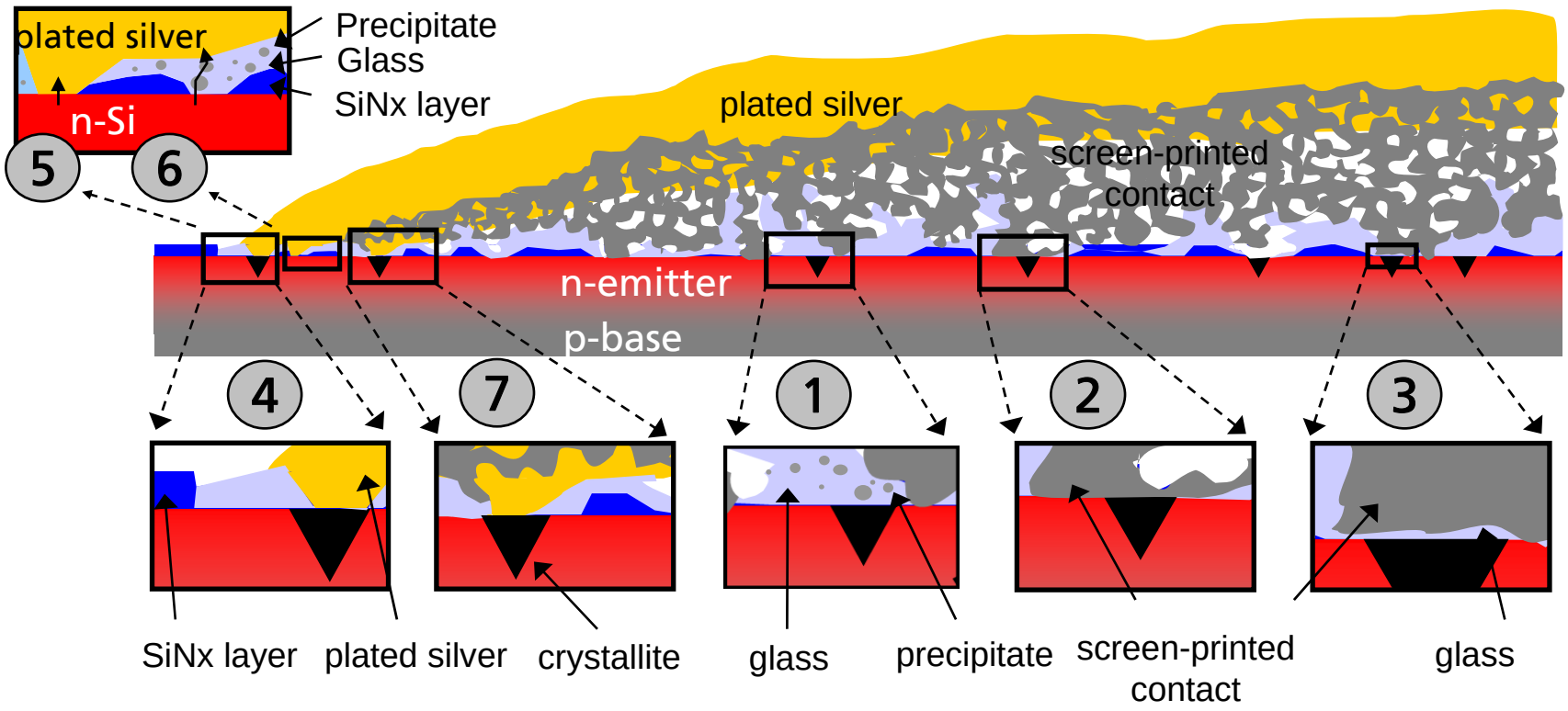
Current model of the contact formation

- Glass melts at about 500°C and wets the interface ink-solar cell
- PbO, dissolved in the glass reacts with the SiNx-layer and opens the ARC
- Both, silver and oxidized silicon is dissolved in the glass melt at about 800°C
- Dissolved silver crystallizes in form of small silver-crystallites during cooling



Schubert, G., *Thick film metallisation of crystalline silicon solar cells 2006,* Universität Konstanz

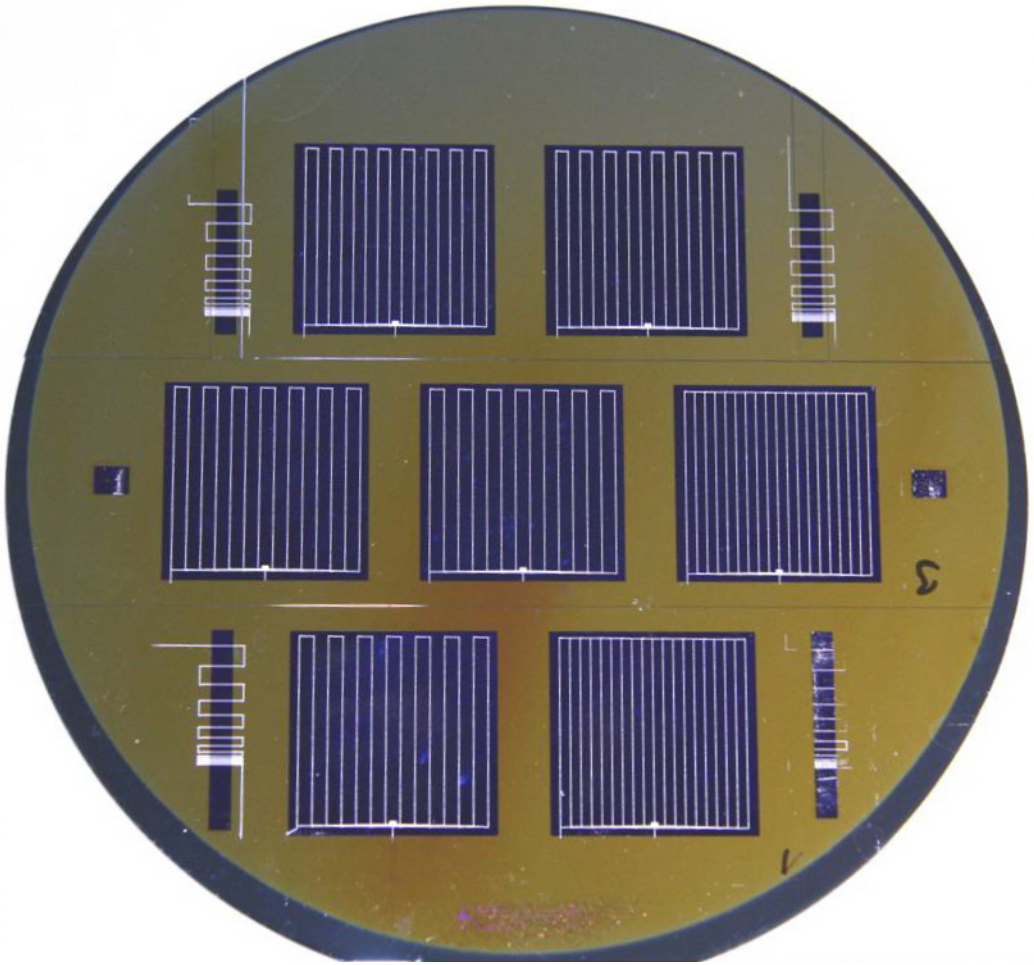
Mögliche Mechanismen des Stromflusses ohne LIP



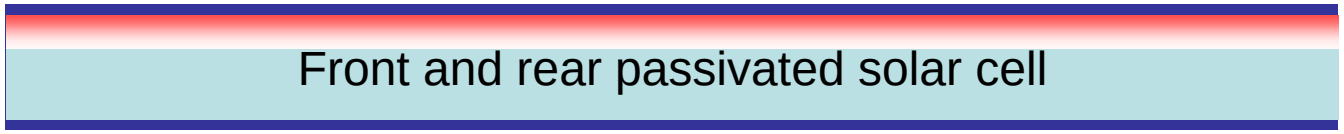
Mette A., *New Concepts for Front Side Metallization of Industrial Silicon Solar Cells,* Universität Freiburg

Solar cells on Fz-Wafers

- Two different inks
  - Diluted screen print paste (ink A)
  - Designed at ISE (ink B)
- On three different emitters
  - 50 Ω/sq.
  - 70 Ω/sq.
  - 110 Ω/sq.



Process flow



Process flow

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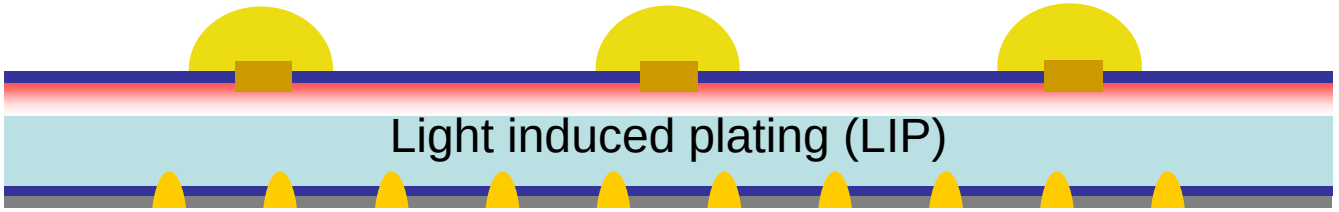

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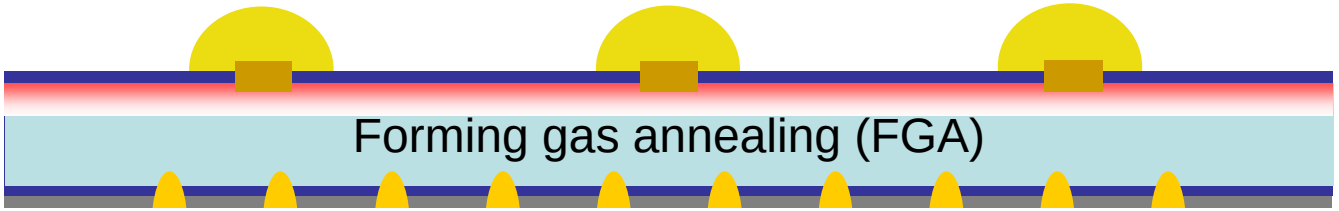
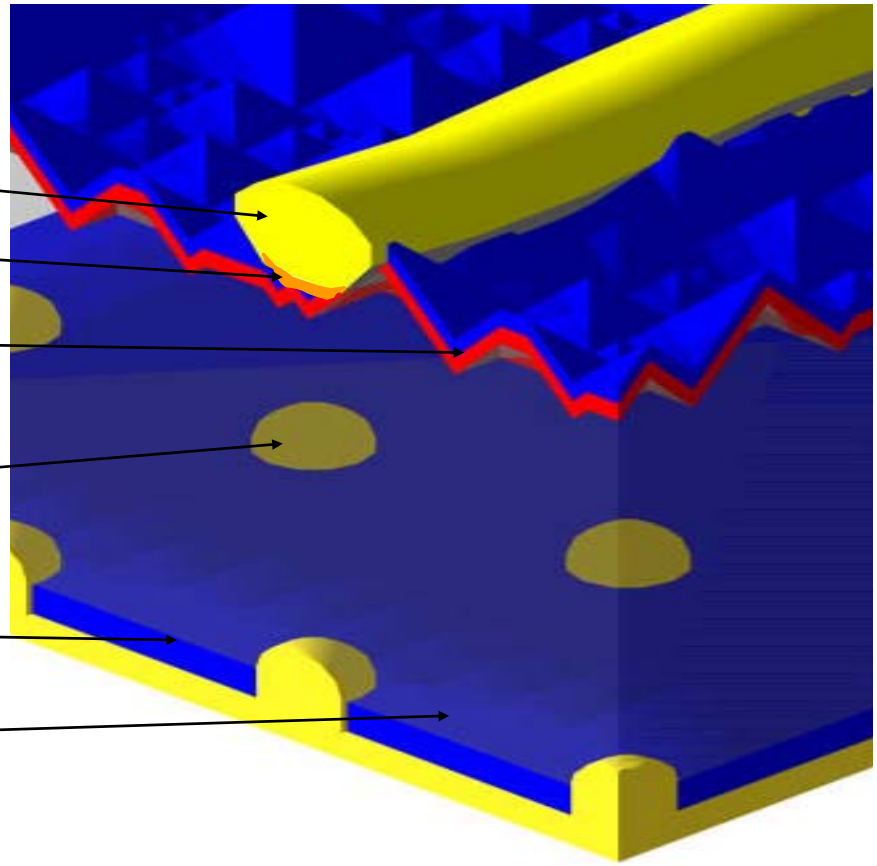
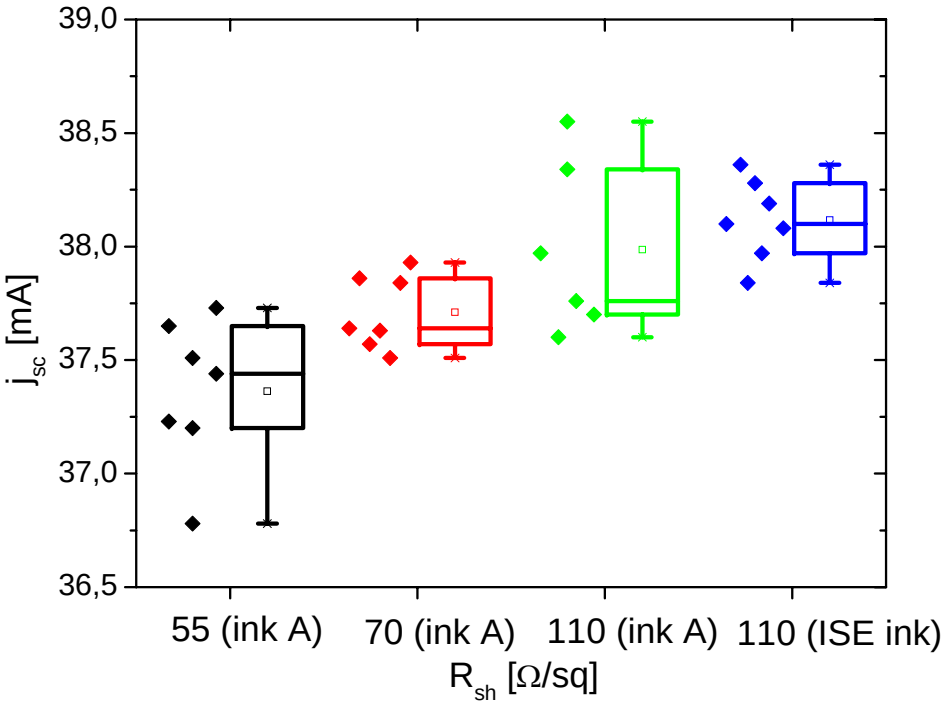


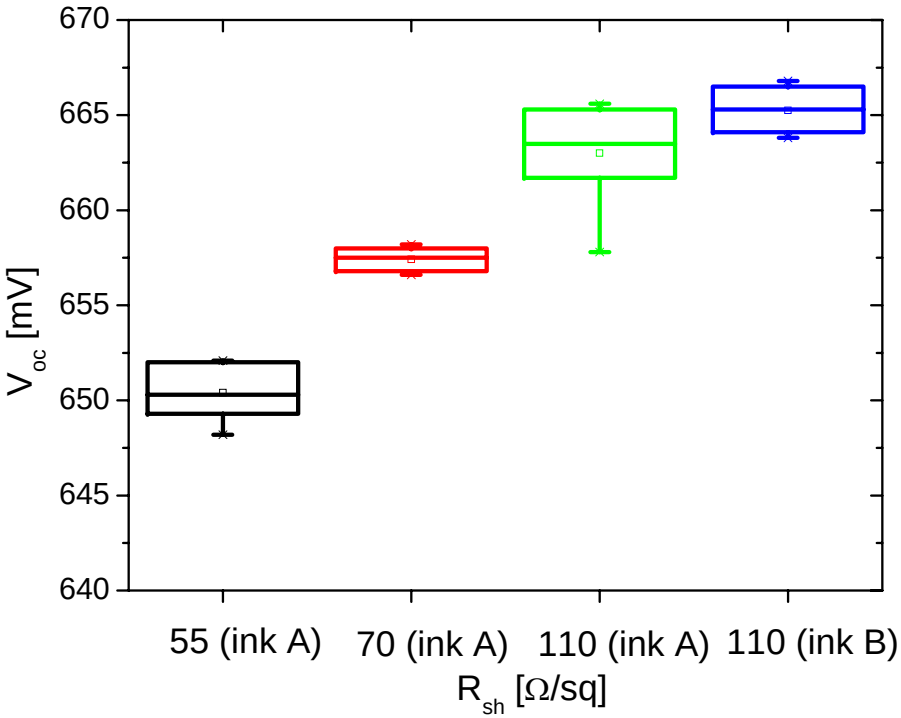
Cell structure

- LIP-Silver
- Aerosol-printed seed layer
- Antireflexion coating and emitter
- LFC point contacts
- Thermal oxide
- Evaporated aluminum



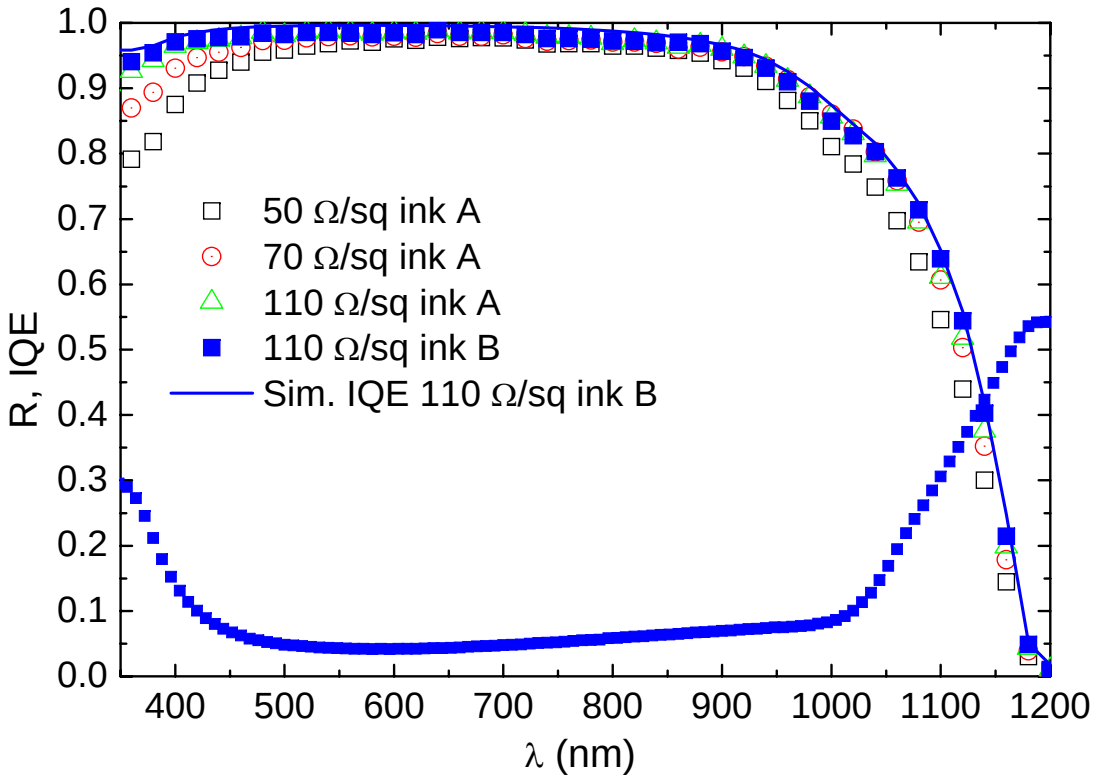
Current and voltage



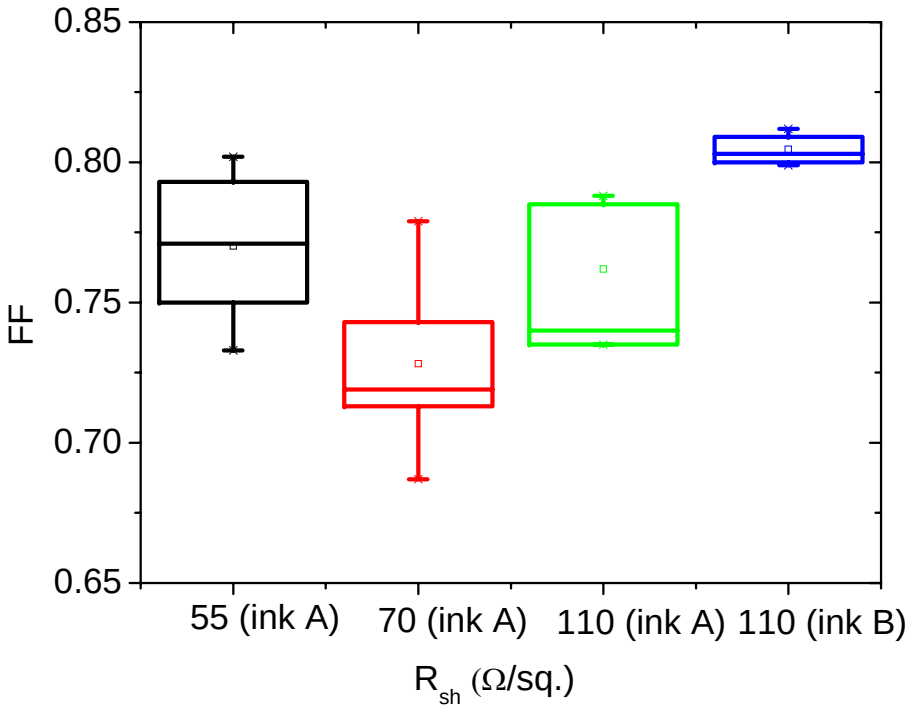


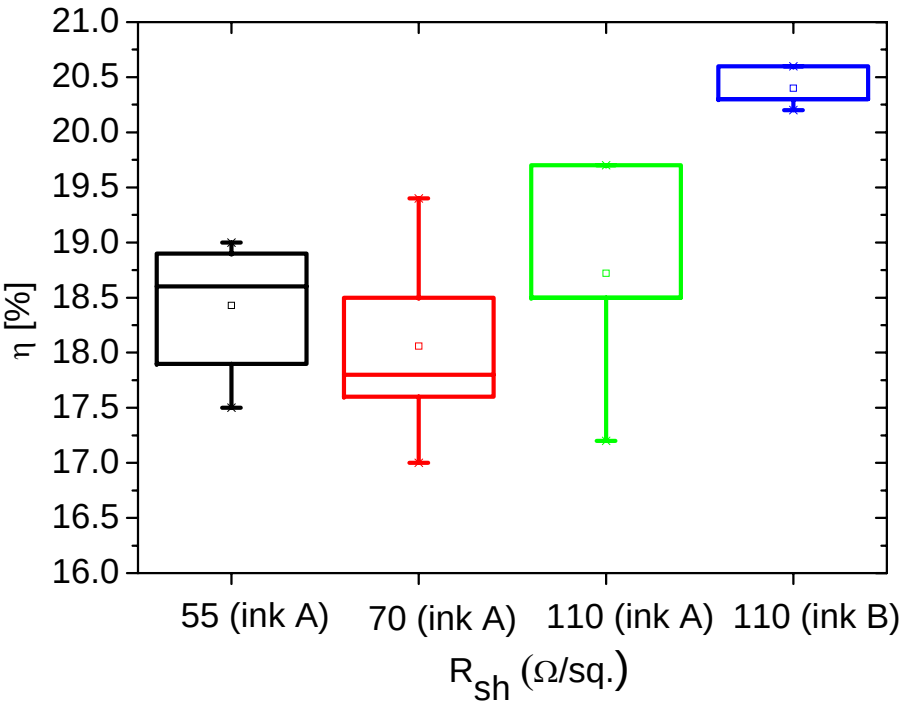
IQE of the best cells of each emitter

- Influence of the emitter sheet resistance is visible in the short wave length region
- Comparable quantum efficiencies for all cells in the long wave length region
- Good reflection, due to a passivated rear and a aluminum mirror

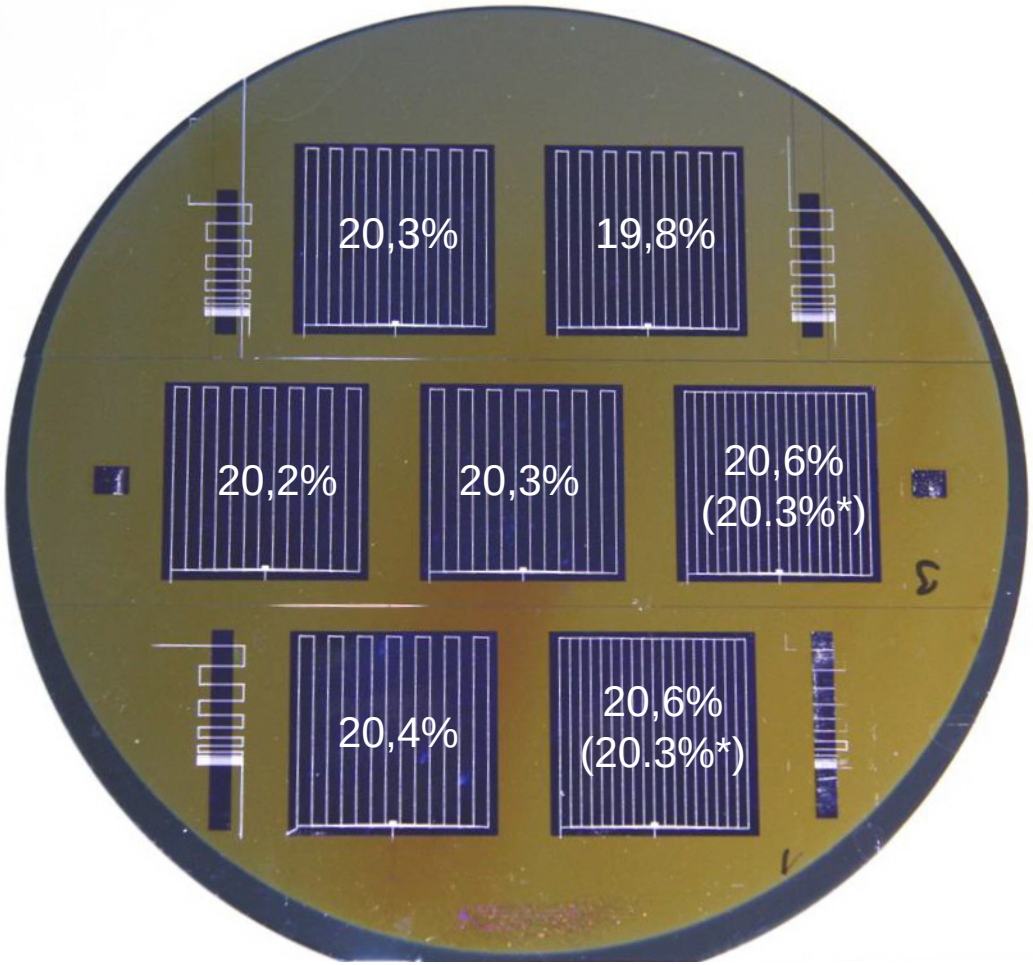


Fill-Factor and efficiency





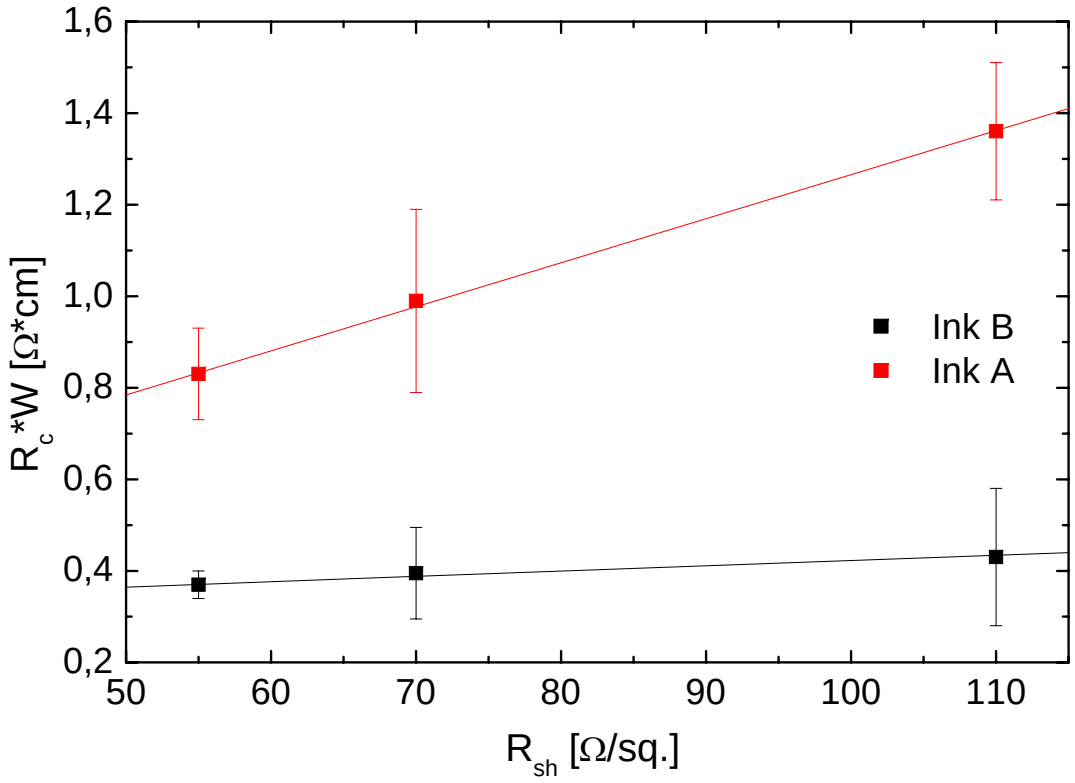
Efficiency over one wafer



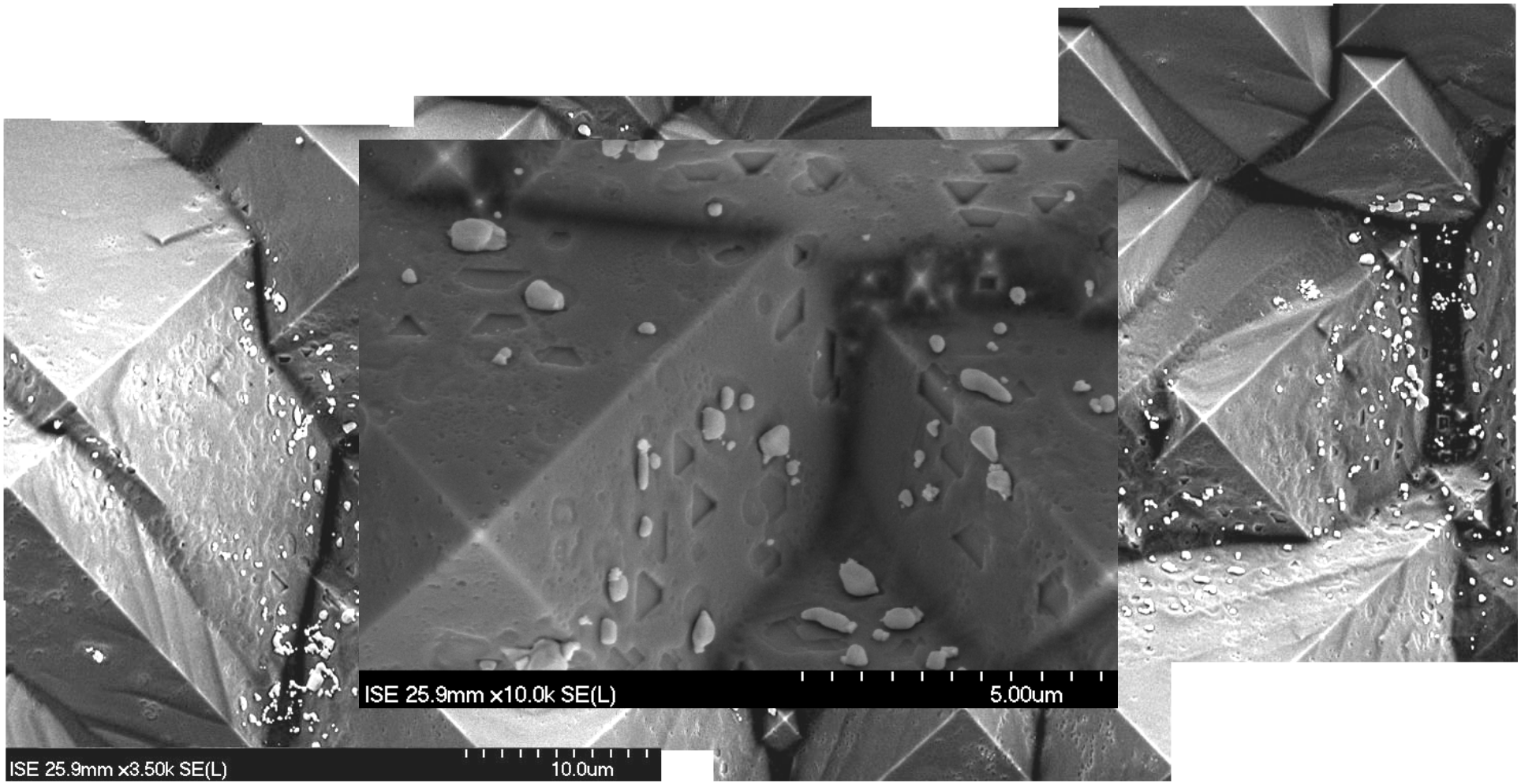
*)independently confirmed by Callab ISE

Contact resistance vs. emitter sheet resistance

- Contact resistance increases with increasing emitter sheet resistance
- The contact resistance $R_c \times W$ for ink B (designed at ISE) is below 0,5 Ωcm for all emitter sheet resistances



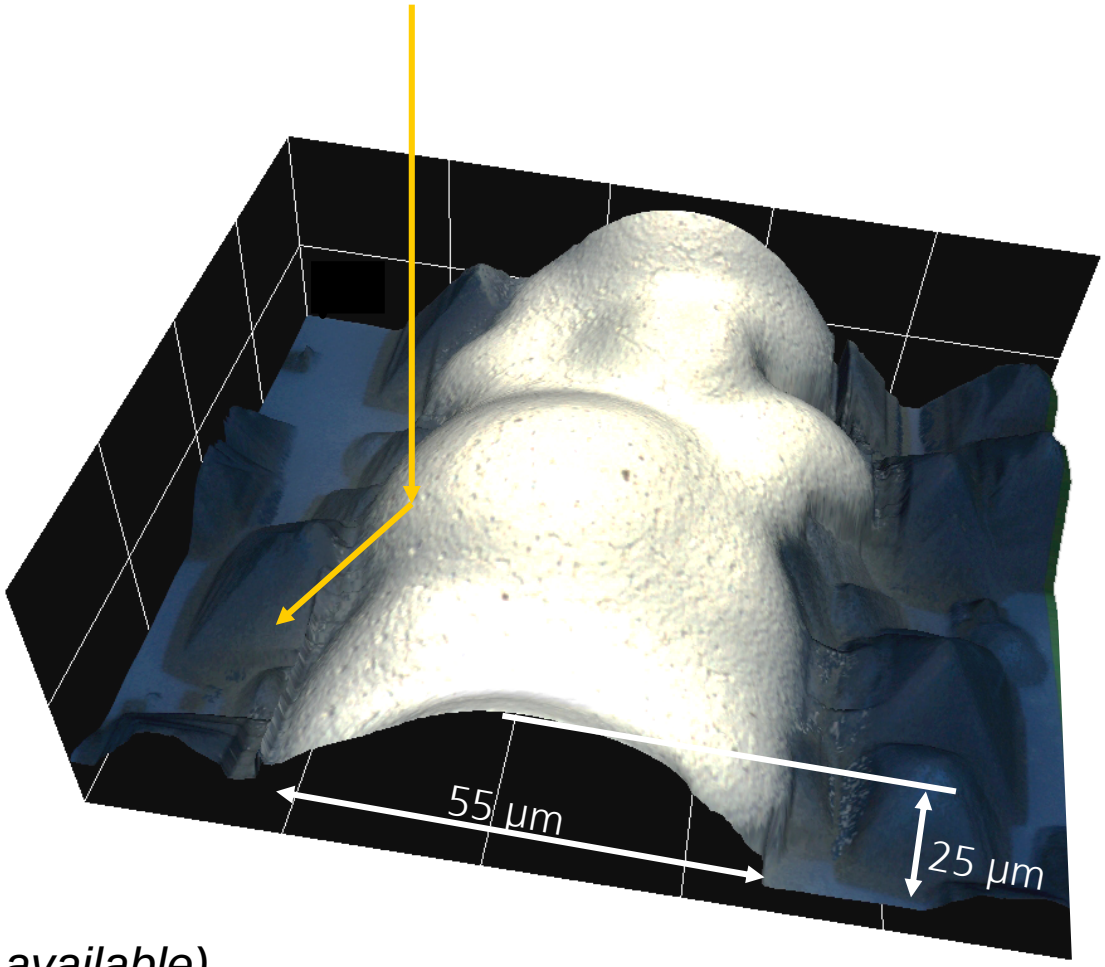
SEM image of Ag-crystallites on a 110 Ω/sq. Emitter



Conclusion

- Fine line printing is possible
- Low ohmic contacts can be formed on lowly doped emitters using ISE ink
- Processed solar cells achieving 20% efficiency

Thank you for your attention



More information:
M. Hörteis, S. W. Glunz PIP-850 (online available)