METALLIZATION OF PASSIVATING AND CARRIER SELECTIVE CONTACTS: STATUS AND PERSPECTIVES AT FRAUNHOFER ISE

M. Bivour, J. Bartsch, F. Clement, G. Cimiotti, D. Erath, F. Feldmann, T. Fellmeth, M. Glatthaar, M. Hermle, M. Jahn, S. Kluska, R. Keding, A. Lorenz, I. Lacmago-Lontchi, S. Mack, A. Moldovan, J. Nekarda, M. Pospischil, A. Rodofili, J. Rentsch, B. Steinhauser, J. Schube, L. Tutsch, W. Wolke and R. Preu, S. W. Glunz

Fraunhofer Institute for Solar Energy Systems ISE

7th Metallization Workshop
Konstanz, 24th October 2017

Fraunhofer ISE

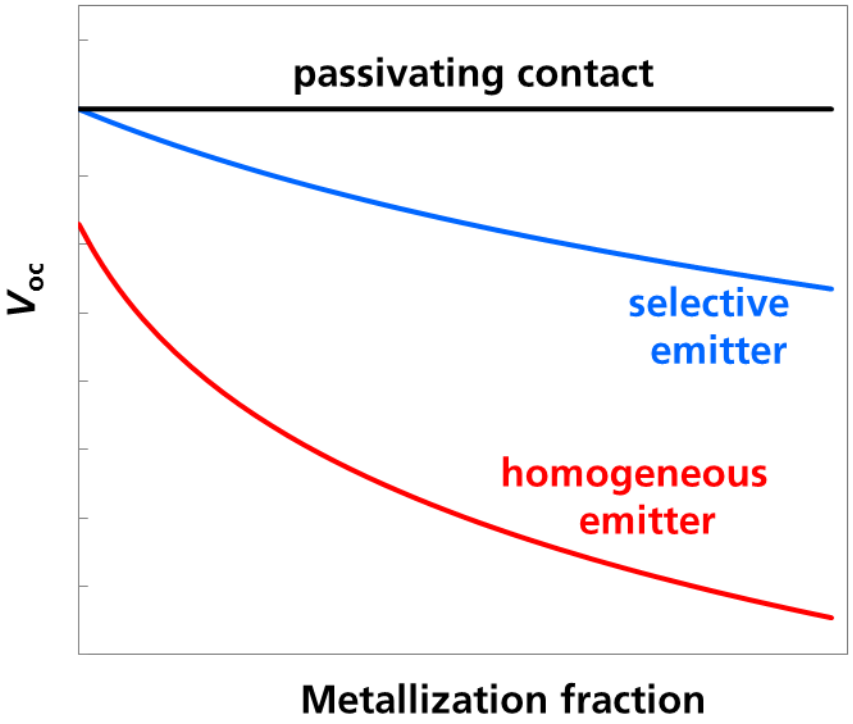
Passivating Contacts
Overcoming Recombination at Metallized Regions

Homojunction + fire-through contacts

- Main stream technology
- Intrinsic efficiency limitation by $J_{0,met} >> J_{0,pass}$

Passivating contacts

- $J_{0,met} = J_{0,pass}$
- Current challenge:
  - Establishing industrial cell process including **metallization** and module integration



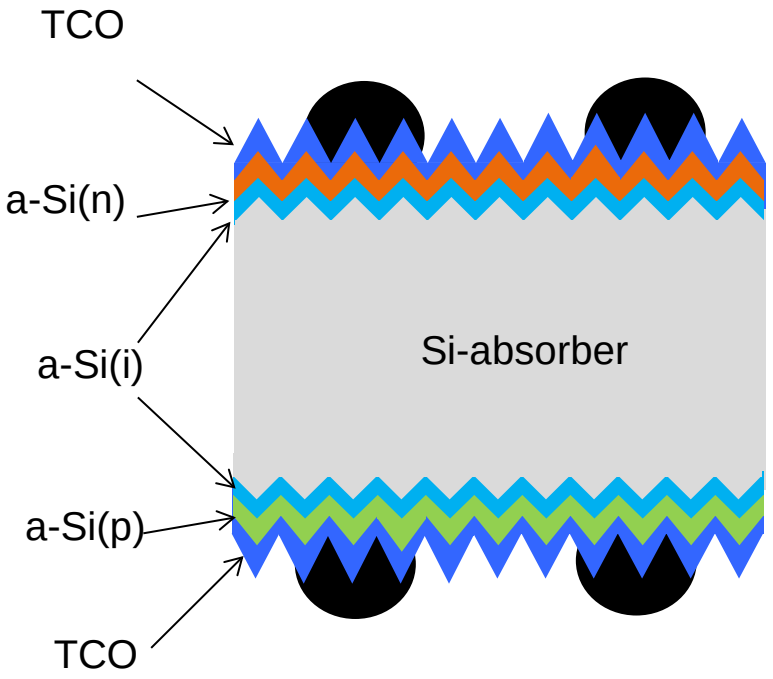
Graph adapted from M. Bivour, PhD thesis, University of Freiburg (2015)

Passivating Contacts
Amorphous Silicon Heterojunction (SHJ)

- Champion efficiencies for c-Si solar cells[1,2]

<u>Back-end process temp. only ~220°C</u>

- Not compatible with main stream c-Si technology
  - Adapted metal electrodes and cells interconnection
  - Lower line conductivity

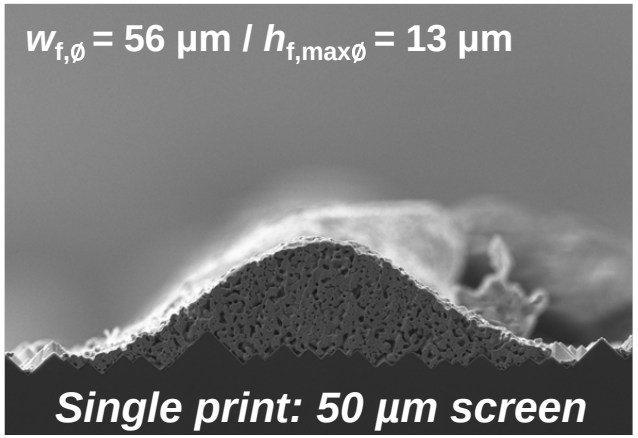


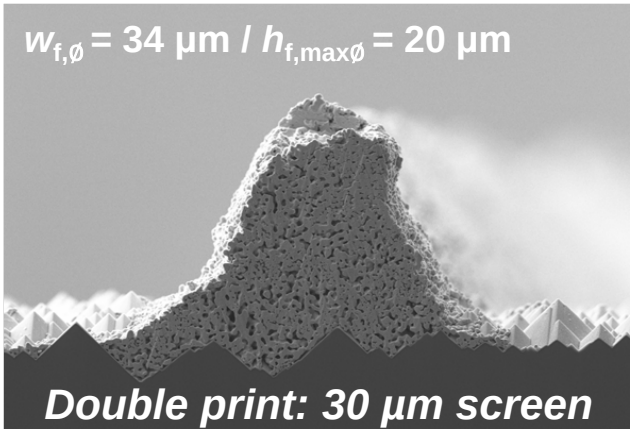
[1]K. Yoshikawa *et al.*, Nature Energy, 2:17032 (2017)

[2]D. Adachi *et al.*, APL, 107, 233506 (2015)

Screen Printing*
Low Temperature Ag Paste

- Various low-T Ag pastes and drying/curing conditions evaluated
- Baseline process: single print
  - Aspect ratio up to 0.3
- Advanced process: double print
  - Aspect ratio up to 0.6
- Finger resistivity ρ_{finger} ~ 6 µΩcm
- Contact resistivity ρ_c < 5 mΩcm^2

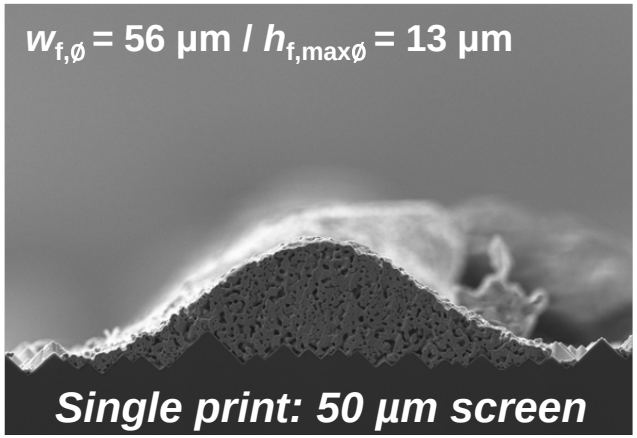




*D. Erath *et al.*, Energy Procedia, 124, 869-874 (2017)

Screen Printing*
Cell Results

- Industrial solar cell precursors
- 5-busbar layout
- Bifacial
- Efficiency up to 21.9%



Metallization	Area [cm²]	V_{OC} [mV]	J_{SC} [mA/cm²]	*FF* [%]	η [%]
Single print (50 µm)	239	727	37.6	80.1	21.9

best cell, 5-busbar, monofacial measurement, black chuck

*D. Erath *et al.*, Energy Procedia, 124, 869-874 (2017)

Ink Jet Printing*

Towards Lower Ag Consumption

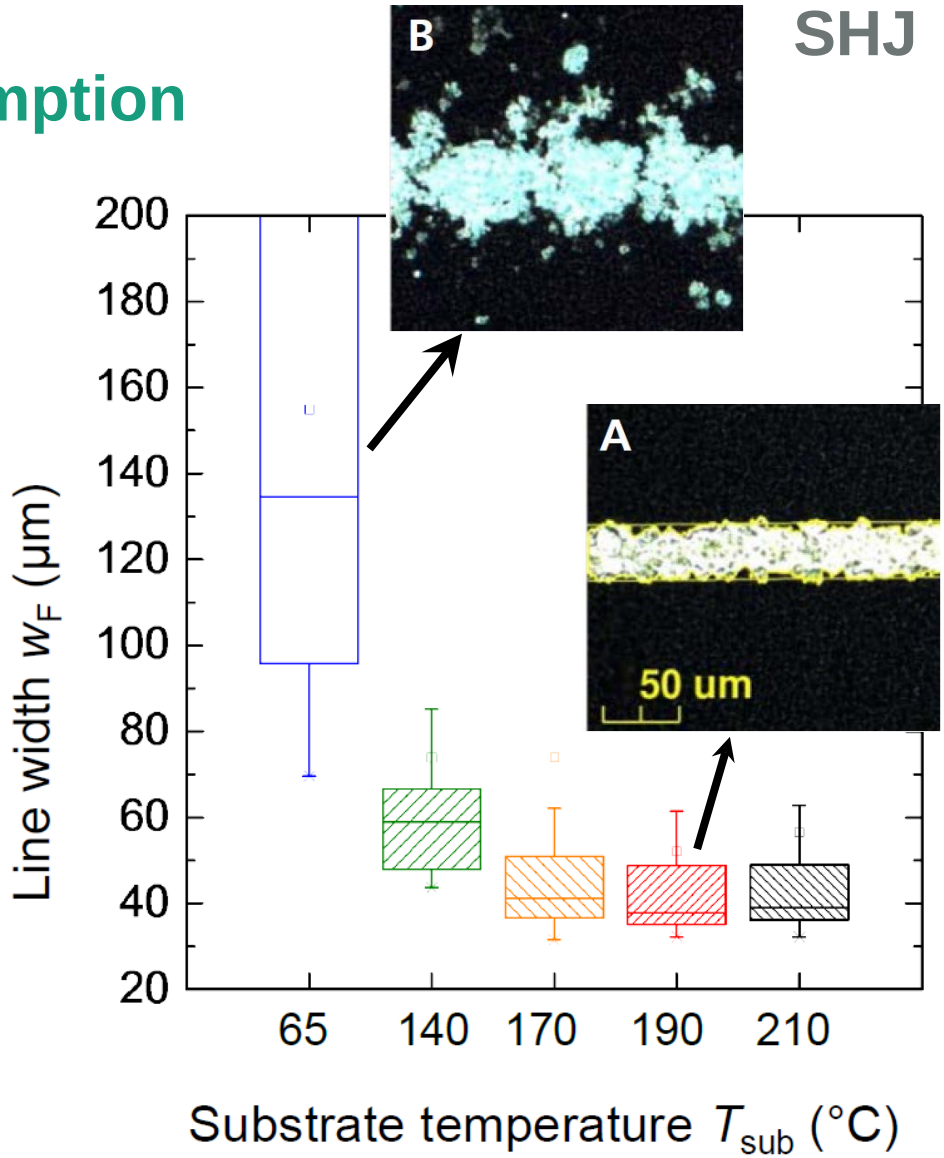
SHJ

- Substrate heating for in-situ drying and ink wetting
- Width down to 32 µm for nano-silver-ink

- To be tested on cell level

→ Multi-busbar layout

→ Seed layer for selective plating using self passivating metal as plating mask[1]



*D. Erath *et al.*, Energy Procedia, 124, 869-874 (2017)

[1]M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

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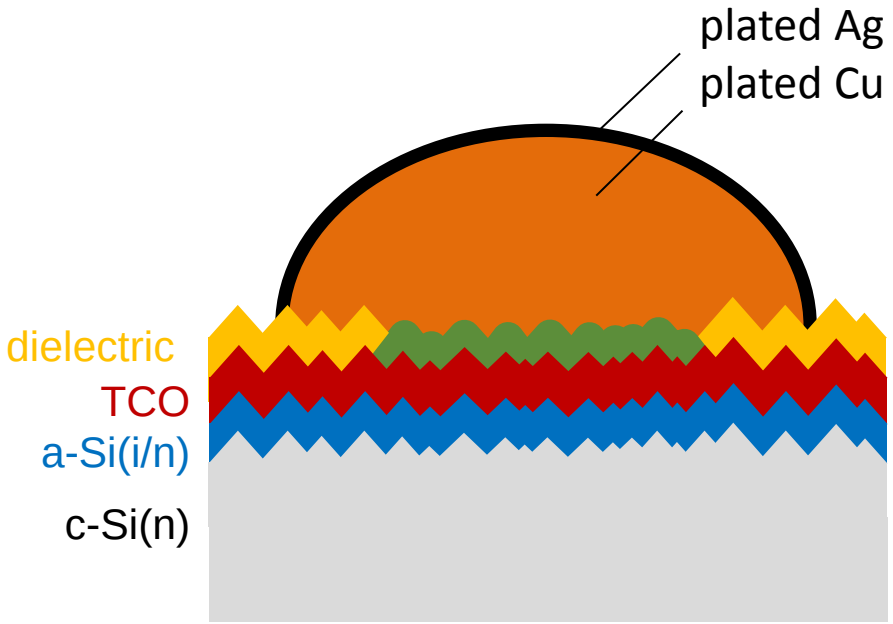
Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ



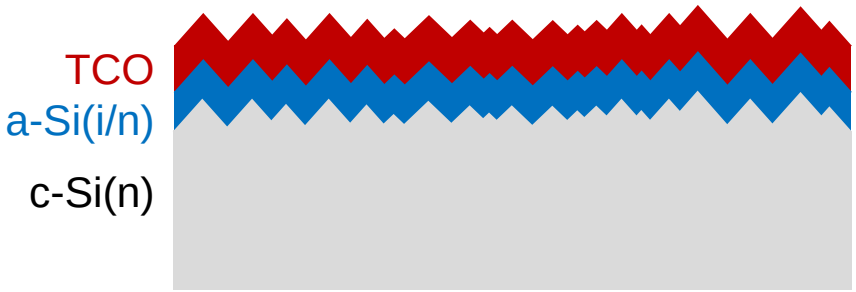
*A. Rodofili *et al.*, Sol. RRL 1 (2017)

Fraunhofer ISE

Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ



*A. Rodofili *et al.*, Sol. RRL 1 (2017)

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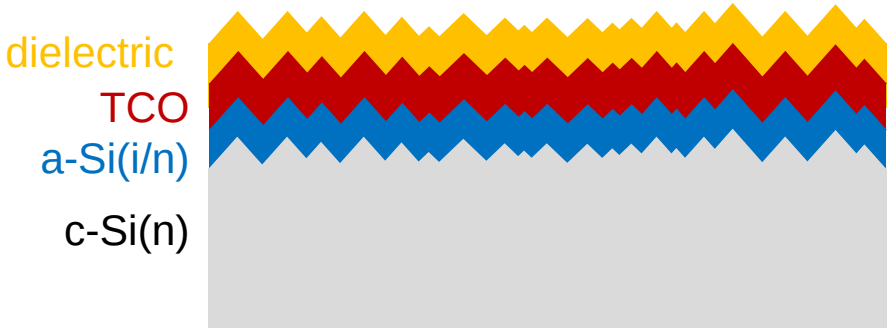
Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ

- Dielectric layer on TCO as plating mask



*A. Rodofili *et al.*, Sol. RRL 1 (2017)

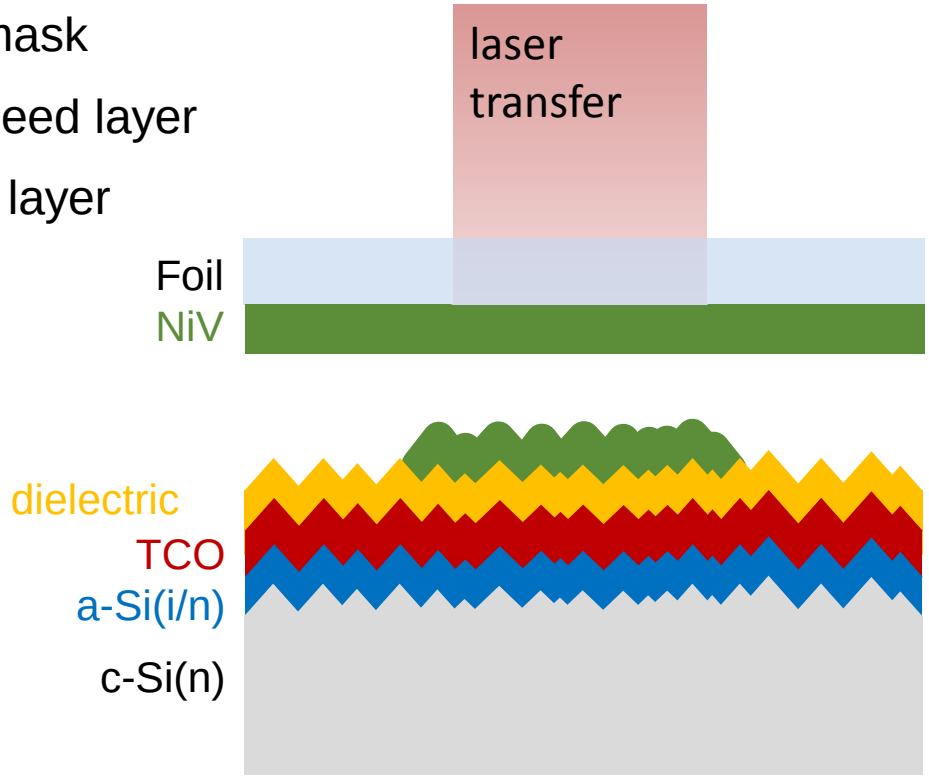
Fraunhofer ISE

Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ

- Dielectric layer on TCO as plating mask
- Laser induced forward transfer[1] of seed layer
  - Transparent plastic foil with NiV layer
  - No laser damage



*A. Rodofili *et al.*, Sol. RRL 1 (2017)

[1]J. Bohandy et al., Journal of Applied Physics **60**, 1538 (1986).

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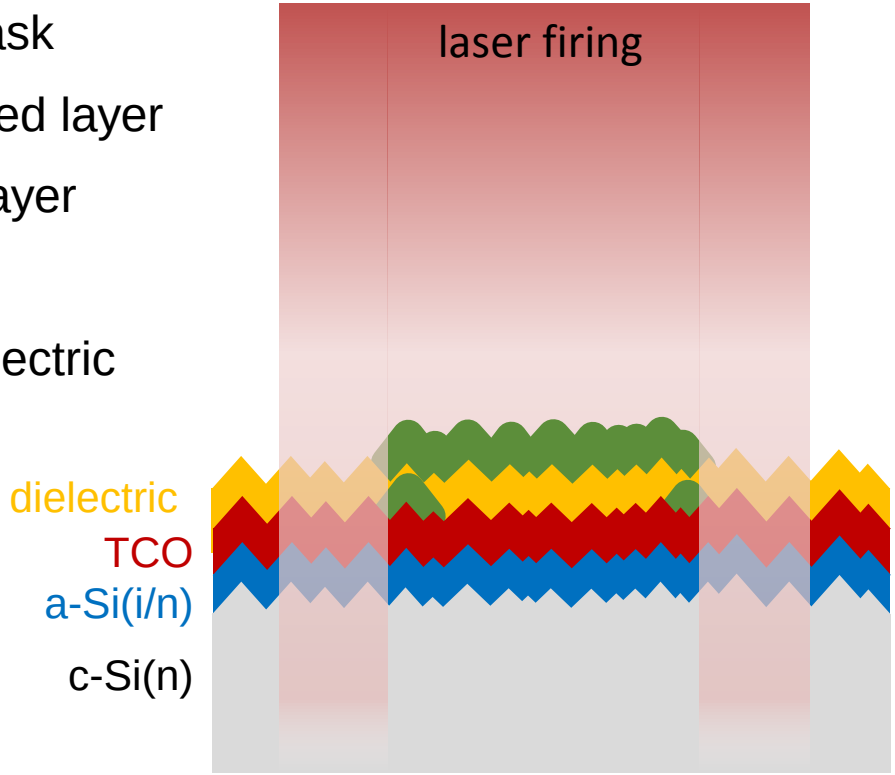
Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ

- Dielectric layer on TCO as plating mask
- Laser induced forward transfer[1] of seed layer
  - Transparent plastic foil with NiV layer
  - No laser damage
- Laser firing of seed layer through dielectric
  - Formation of contact to TCO
  - No laser damage



*A. Rodofili *et al.*, Sol. RRL 1 (2017)

[1]J. Bohandy et al., Journal of Applied Physics **60**, 1538 (1986).

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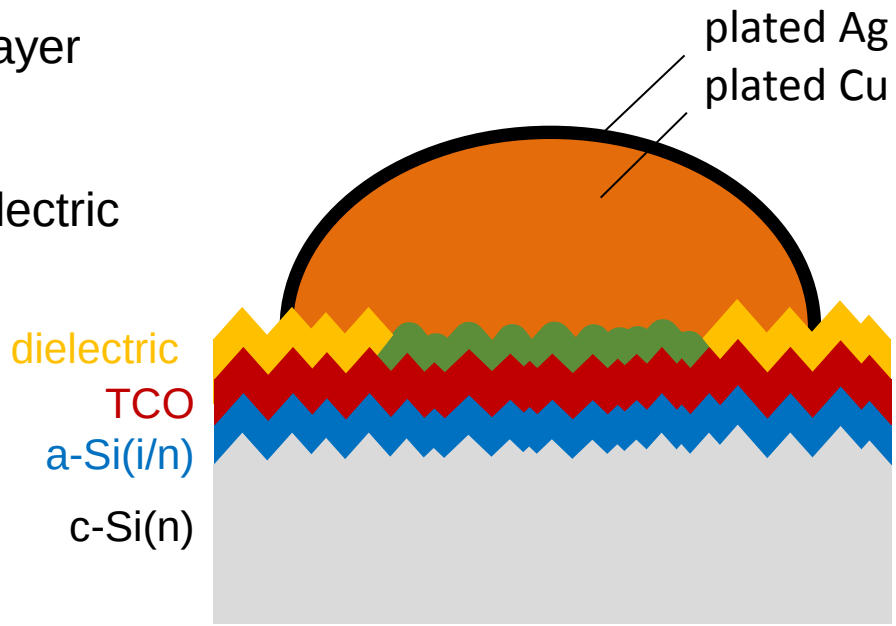
Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ

- Dielectric layer on TCO as plating mask
- Laser induced forward transfer[1] of seed layer
  - Transparent plastic foil with NiV layer
  - No laser damage
- Laser firing of seed layer through dielectric
  - Formation of contact to TCO
  - No laser damage
- Pulse plating to reduce parasitic plating[2]



*A. Rodofili *et al.*, Sol. RRL 1 (2017)

[1]J. Bohandy et al., Journal of Applied Physics 60, 1538 (1986)

[2]M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

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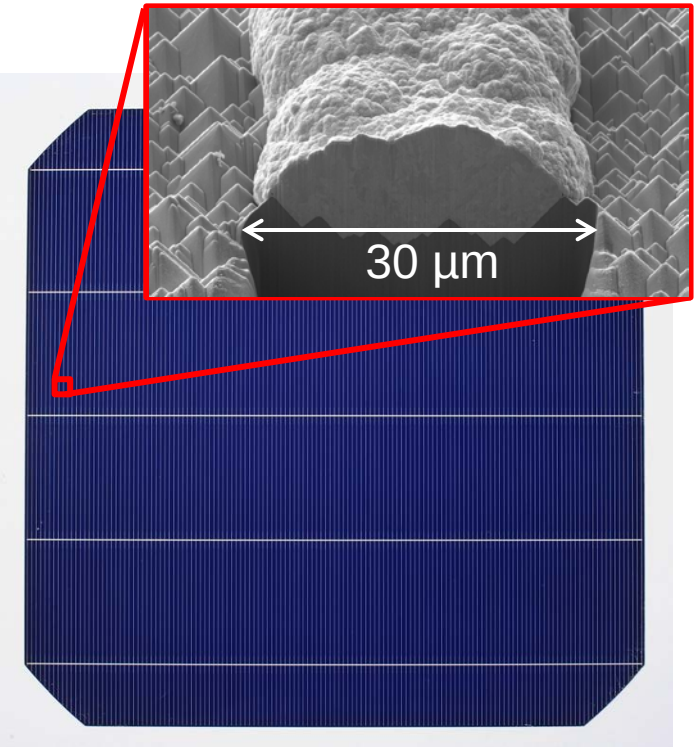
Laser Transfer and Firing of Seed Layer (LTF) + Plating*

Overcoming the Need for Plating Resist

SHJ

- Industrial precursors
- 5-busbar layout
- Monofacial
- Encouraging result for first cell batch
  - No laser damage
  - Optics and electrics improved compared to screen printing reference



Metallization	Area [cm²]	V_{OC} [mV]	J_{SC} [mA/cm²]	*FF* [%]	η [%]
Screen printing	239	727	37.8	79.1	21.7
LTF + Cu plating	239	728	38.0	80.1	22.2

best cells, 5 busbar, monofacial, industrial precursors

*A. Rodofili *et al.*, Sol. RRL 1 (2017)

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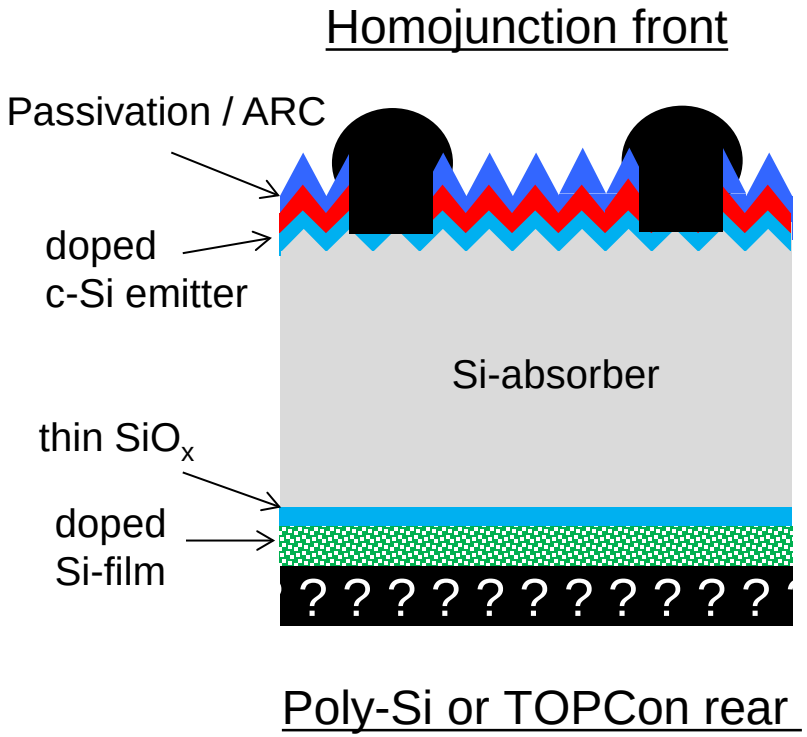
Passivating Contacts*
Poly-Si and TOPCon

Back-end process temp. **>** 220°C

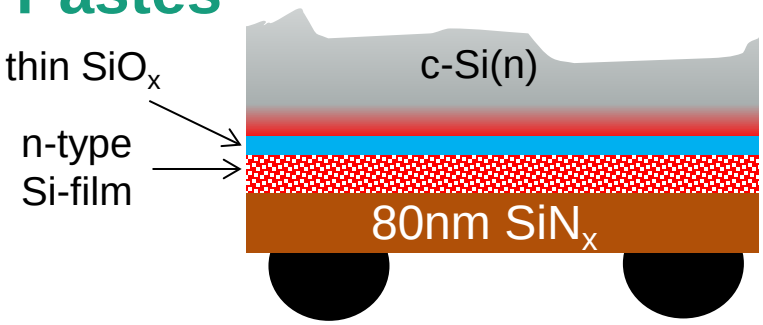
- Potentially, more compatible with main stream technology
- Currently, evaluation of suitable back-end processes



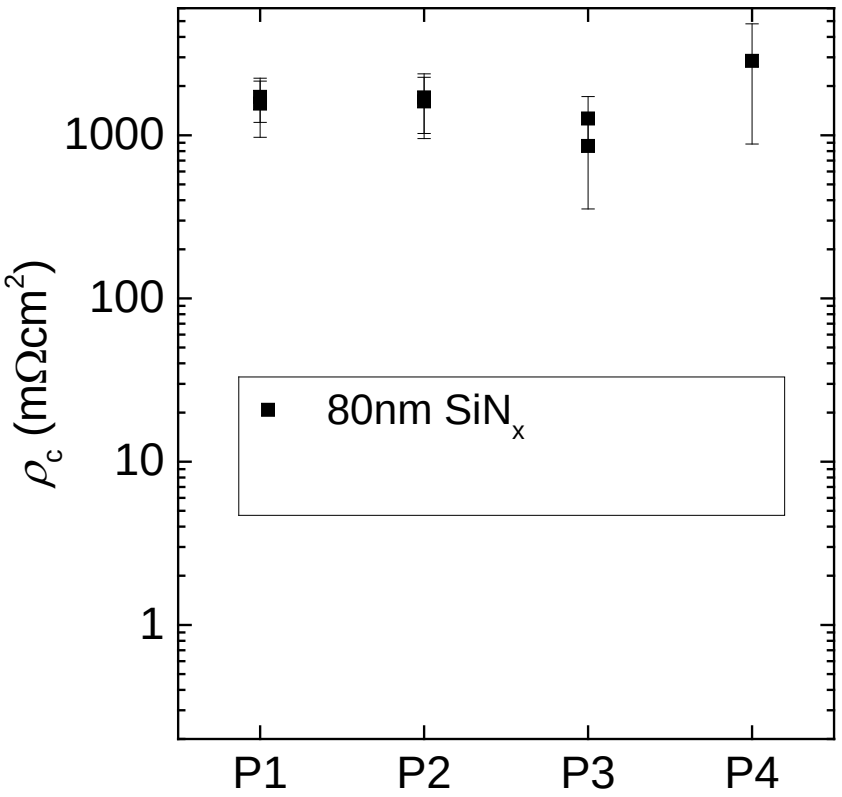
*Y. Kwark PhD thesis, Stanford Univ. (1985)
*F. Feldmann *et al*., SOLMAT, 120, 270-274 (2014)
*U. Römer *et al*., SOLMAT, 131, 85-91 (2014)

40nm n-type TOPCon

800°C Firing of Commercial Ag Screen Printing FT Pastes



- SiN_x capping
  - Poor contact



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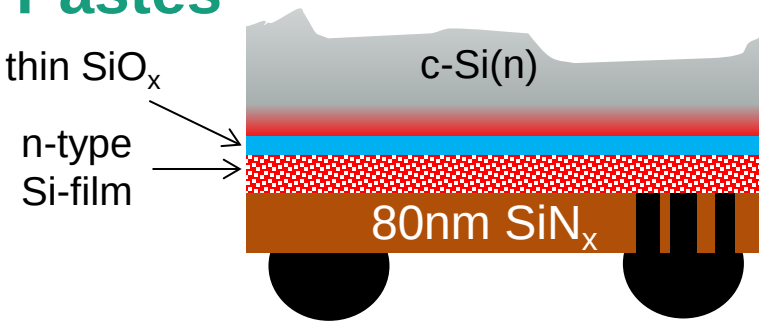

- SiN_x capping
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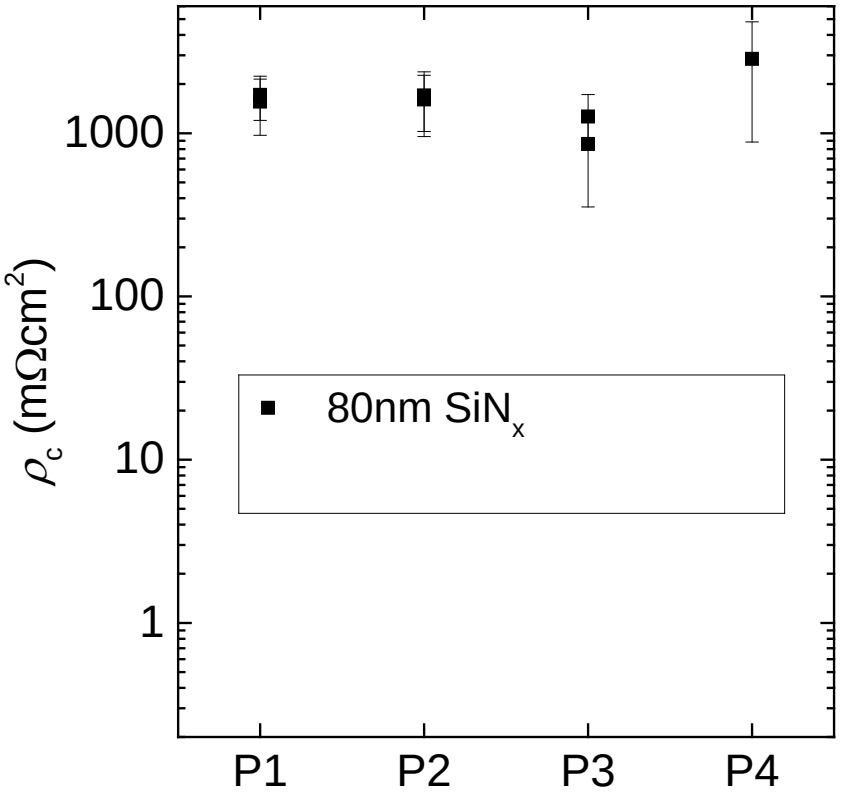

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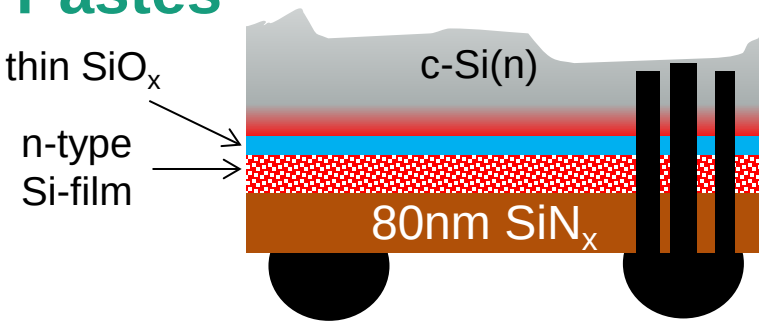
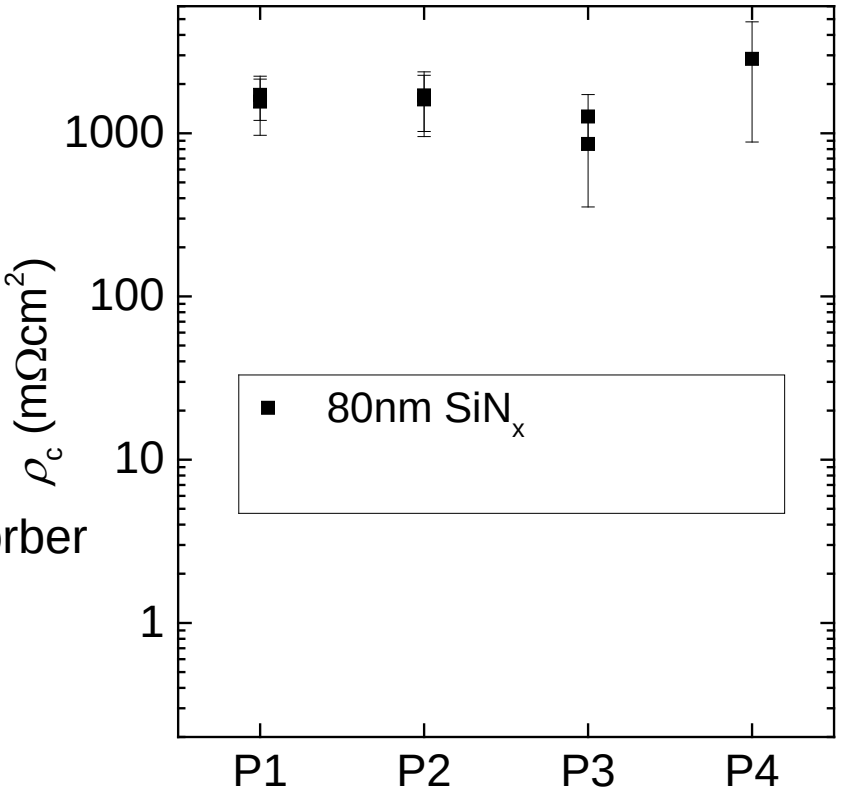


- SiN_x capping
  - Poor contact
  - Likely, contact to lowly doped absorber



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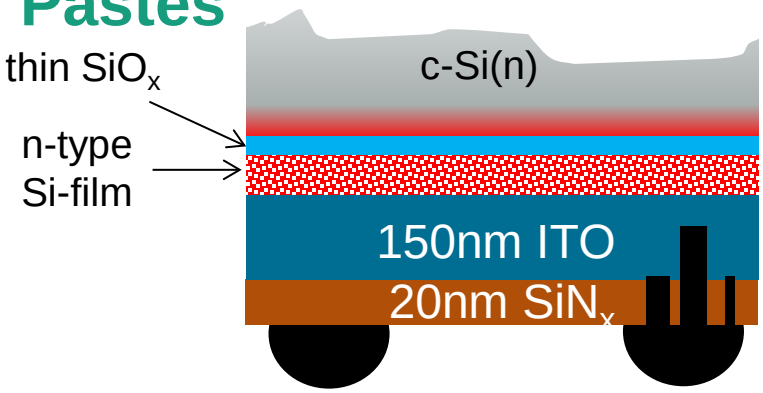
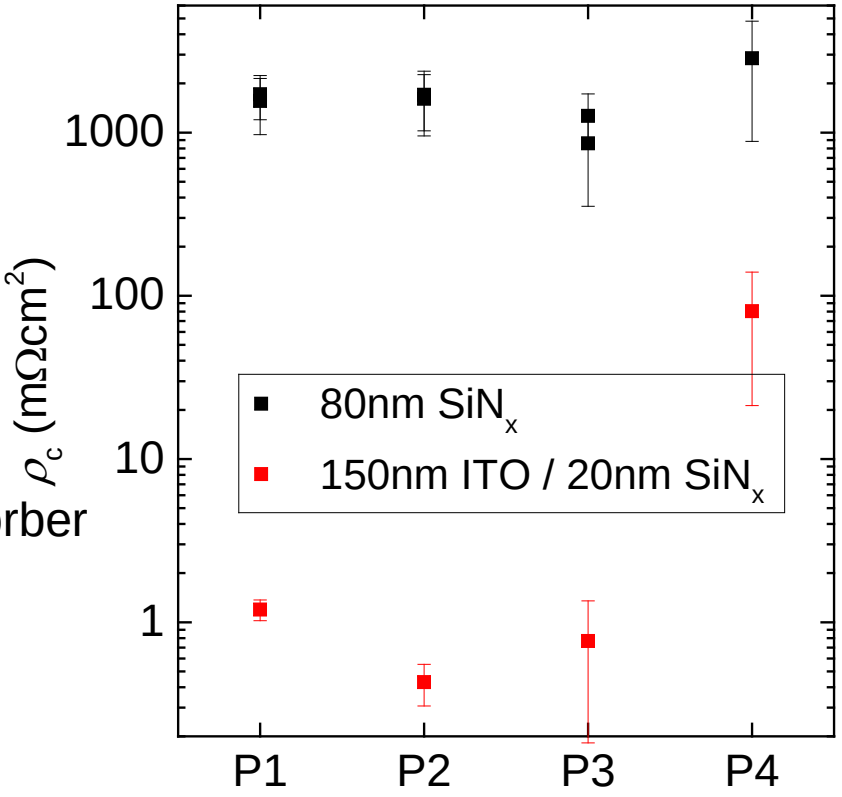
40nm n-type TOPCon

800°C Firing of Commercial Ag Screen Printing FT Pastes



- SiN_x capping
  - Poor contact
  - Likely, contact to lowly doped absorber
- ITO / SiN_x capping
  - Very good contact
  - Likely, contact to highly doped ITO or Si-film



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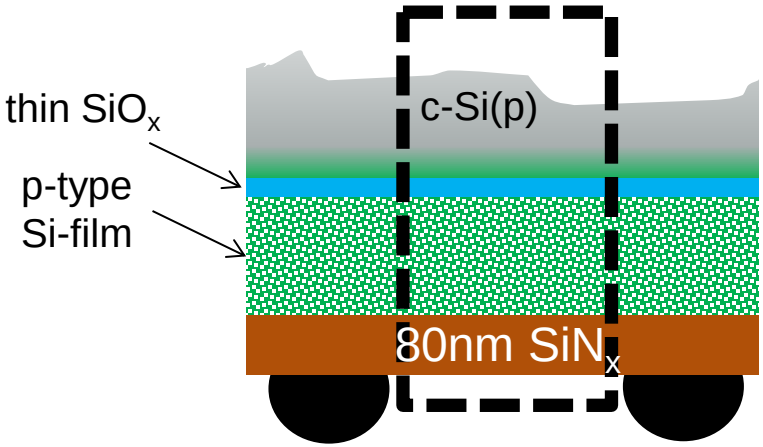
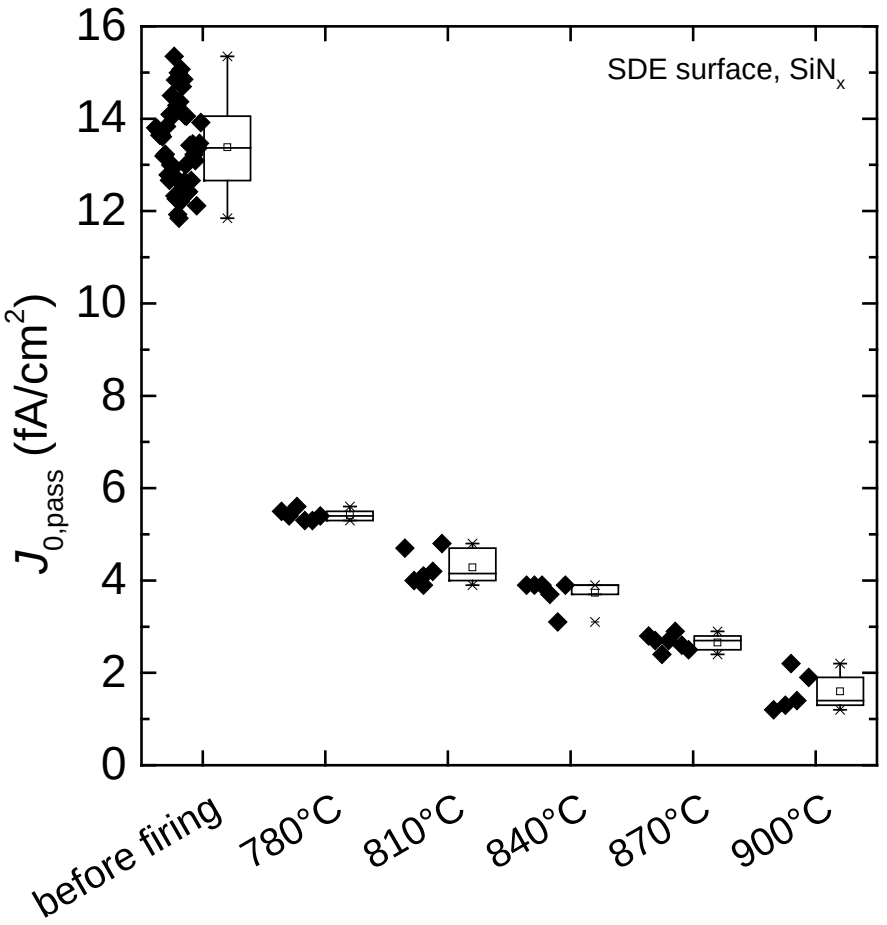
300nm p-type Poly-Si*

Firing of Commercial Ag Screen Printing FT Pastes



- Low $J_{0,pass}$



*S. Mack et al., EUPVSEC, (2017)

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300nm p-type Poly-Si*

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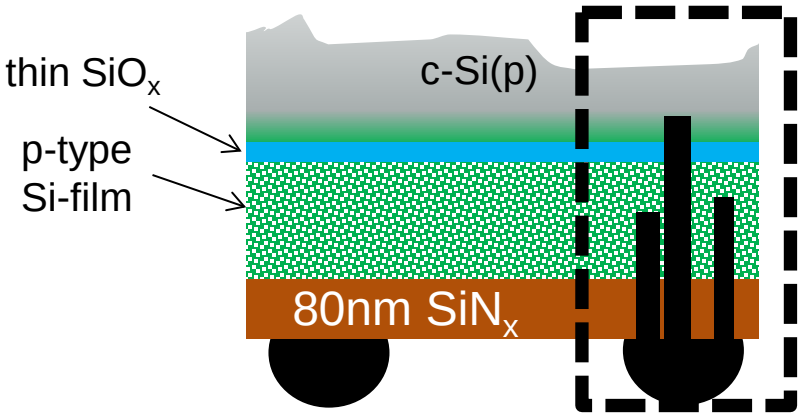
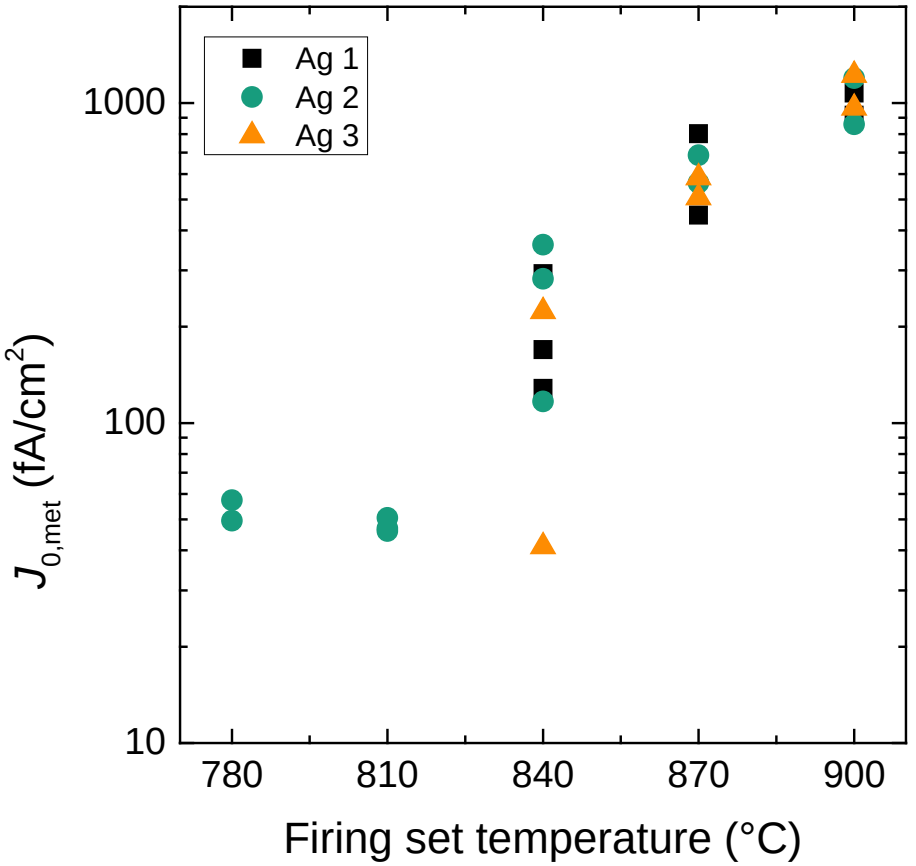


- Low $J_{0,pass}$
- $J_{0,met}$ increases with T_{firing}
  - $J_{0,met}$ >> $J_{0,pass}$



*S. Mack et al., EUPVSEC, (2017)

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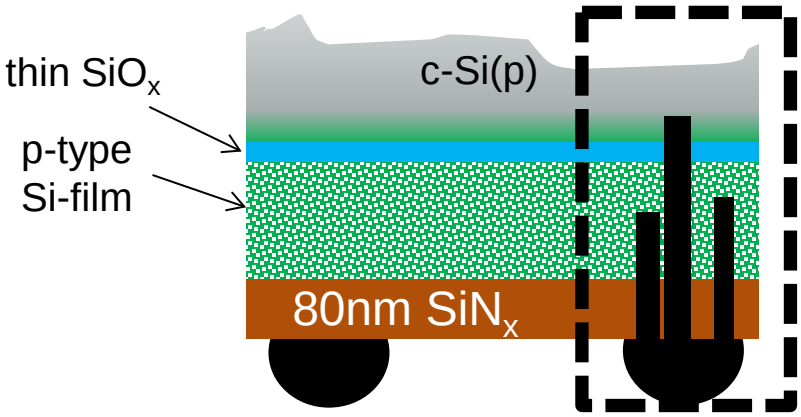
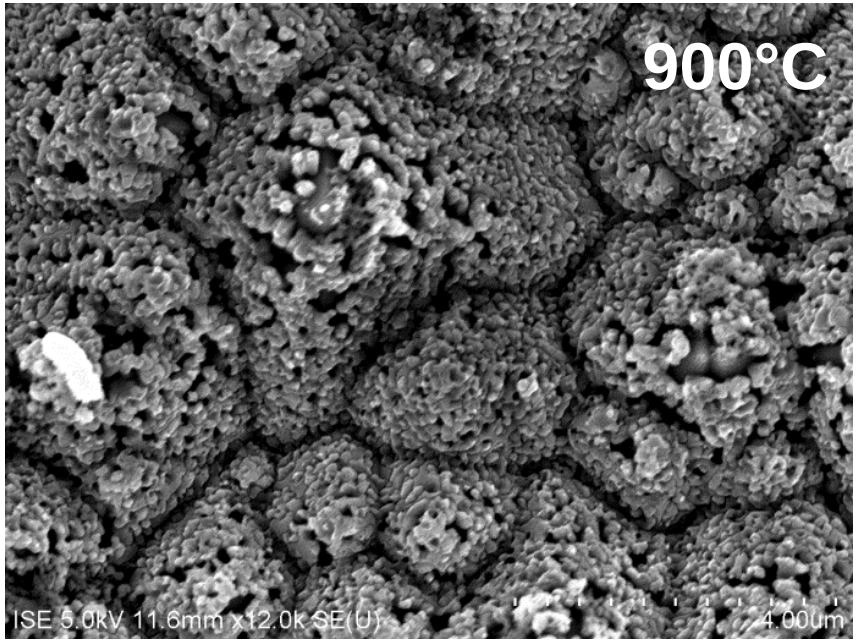


- Low $J_{0,pass}$
- $J_{0,met}$ increases with T_{firing}
  - $J_{0,met}$ >> $J_{0,pass}$
- Local penetration / damage of poly-Si*,[1]



*S. Mack et al., EUPVSEC, (2017)

[1]H.E. Çiftpinar *et al.*, Energy Procedia, 124, 851-861 (2017)

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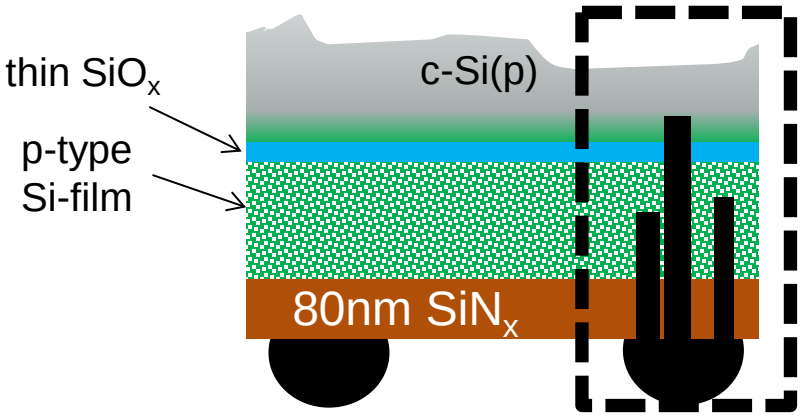
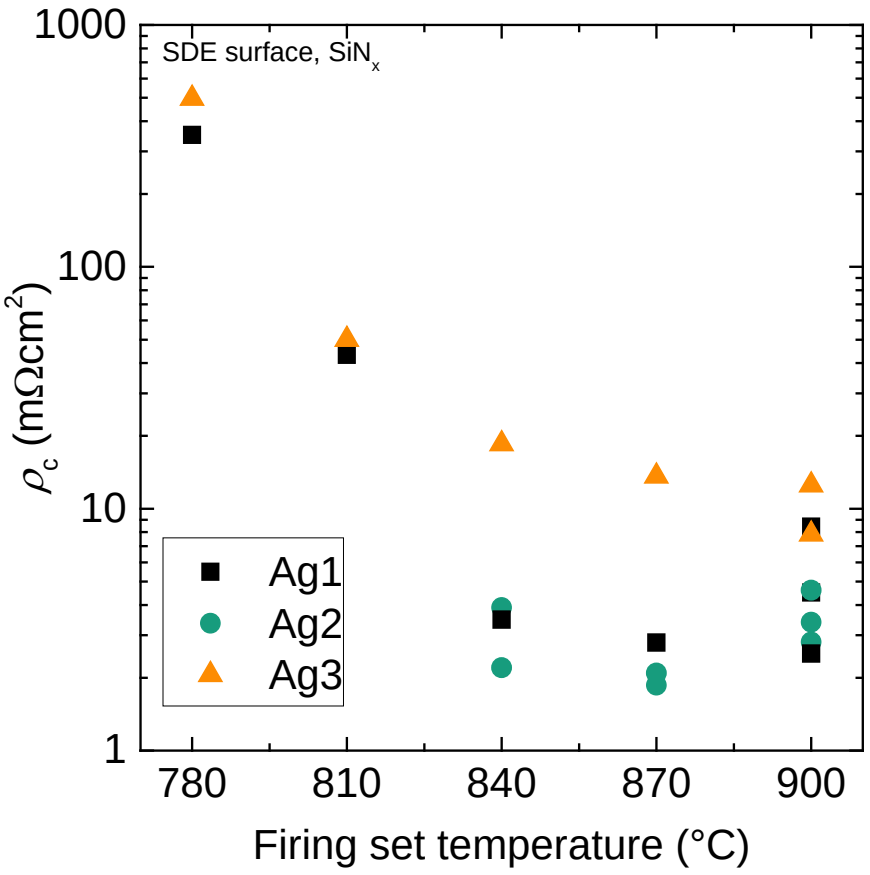
300nm p-type Poly-Si*

Firing of Commercial Ag Screen Printing FT Pastes



- Low $J_{0,pass}$
- $J_{0,met}$ increases with T_{firing}
  - $J_{0,met}$ >> $J_{0,pass}$
- Local penetration / damage of poly-Si*,[1]
- Low ρ_c for Ag2



*S. Mack et al., EUPVSEC, (2017)

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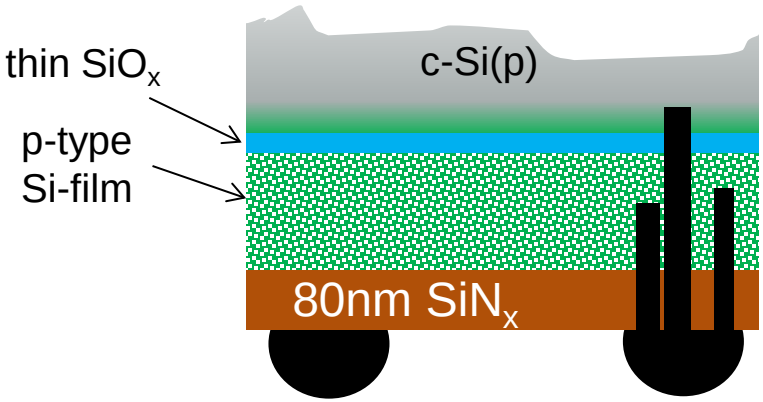
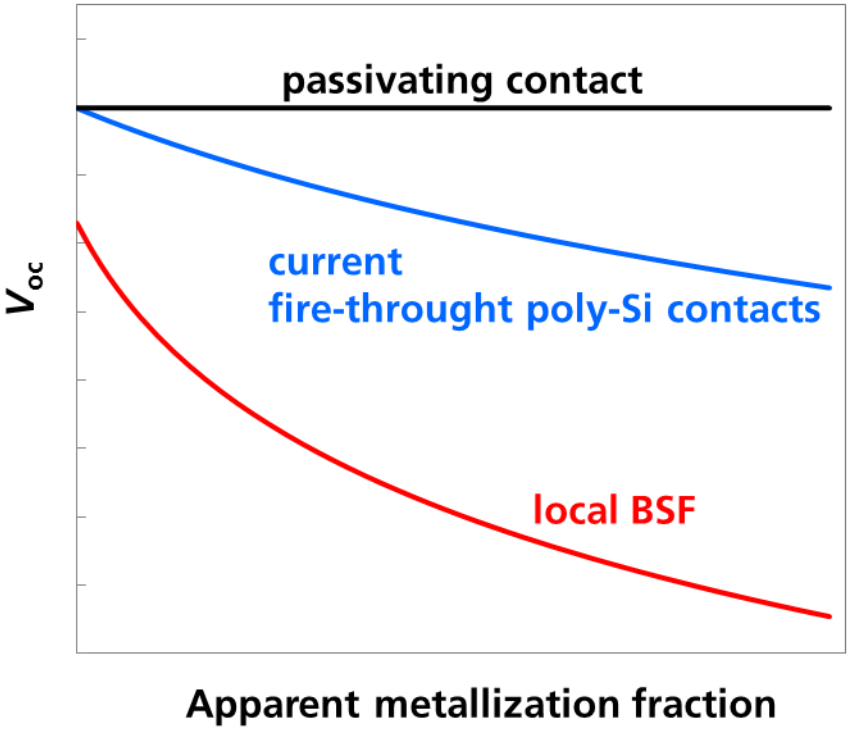
300nm p-type Poly-Si
Firing of Commercial Ag Screen Printing FT Pastes



- 840°C
  - $J_{0,pass} \approx 5fA/cm^2$
  - $J_{0,met} \approx 250fA/cm^2$
  - $\rho_c = 2m\Omega cm^2$



*S. Mack et al., EUPVSEC, (2017)

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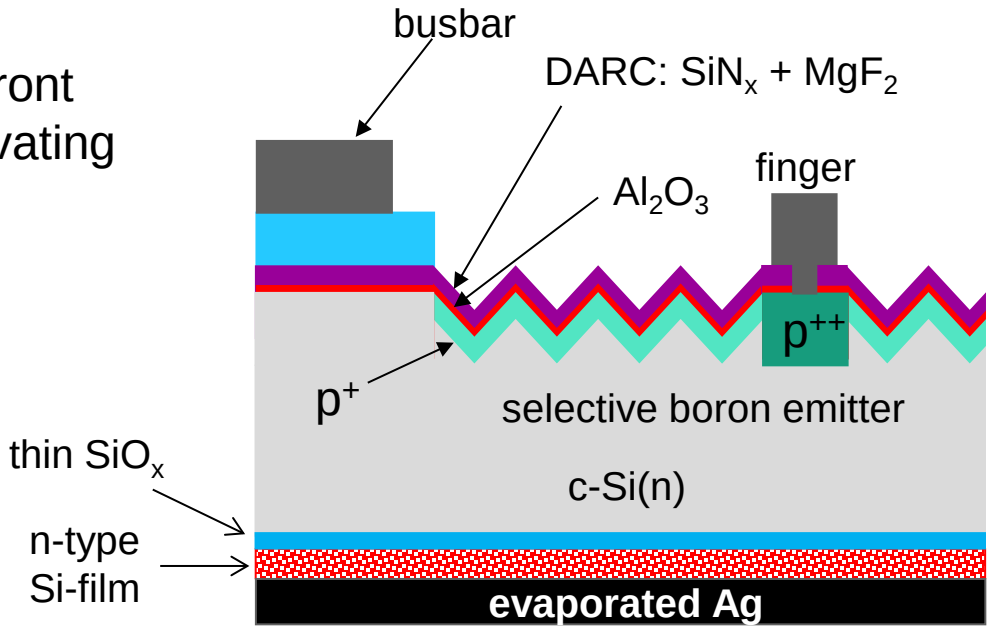
Non-Firing Approach: Evaporated Ag
High Efficiency Front Side Required

- High efficiency homojunction front essential to benefit from passivating contact at rear
- TOPCon + evaporated Ag
  - $J_{0,met} = J_{0,pass}$
  - 25.8%[1] lab-type cells



Metallization Front / Rear	Area [cm²]	V_{oc} [mV]	J_{sc} [mA/cm²]	*FF* [%]	η [%]
Photolithography / evaporated Ag	4 (da)	724	42.9	83.1	25.8[1]

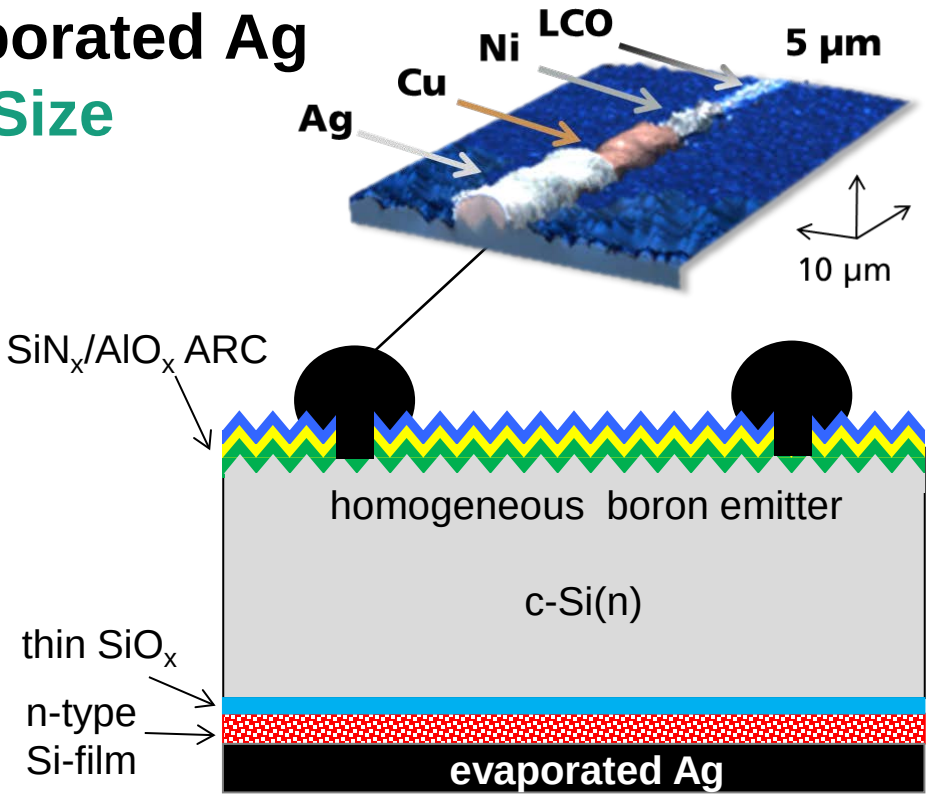
Certified by Fraunhofer ISE CalLab, da: designated area

[1]A. Richter *et al.*, EUPVSEC, (2017)

Non-Firing Approach: Evaporated Ag

First Cell Batch Practicale Size

- Homogeneous boron emitter
- LCO + Cu-plating front side
- TOPCon + evaporated Ag
  - 22.9%[1]



Metallization Front / Rear	Area [cm²]	V_{oc} [mV]	J_{sc} [mA/cm²]	*FF* [%]	η [%]
LCO + Cu-plating / evaporated Ag	100 (ap)	694	40.8	81.0	22.9[1]

In-house measurement, ap: aperture area

[1]F. Feldmann *et al.*, EUPVSEC, (2017)

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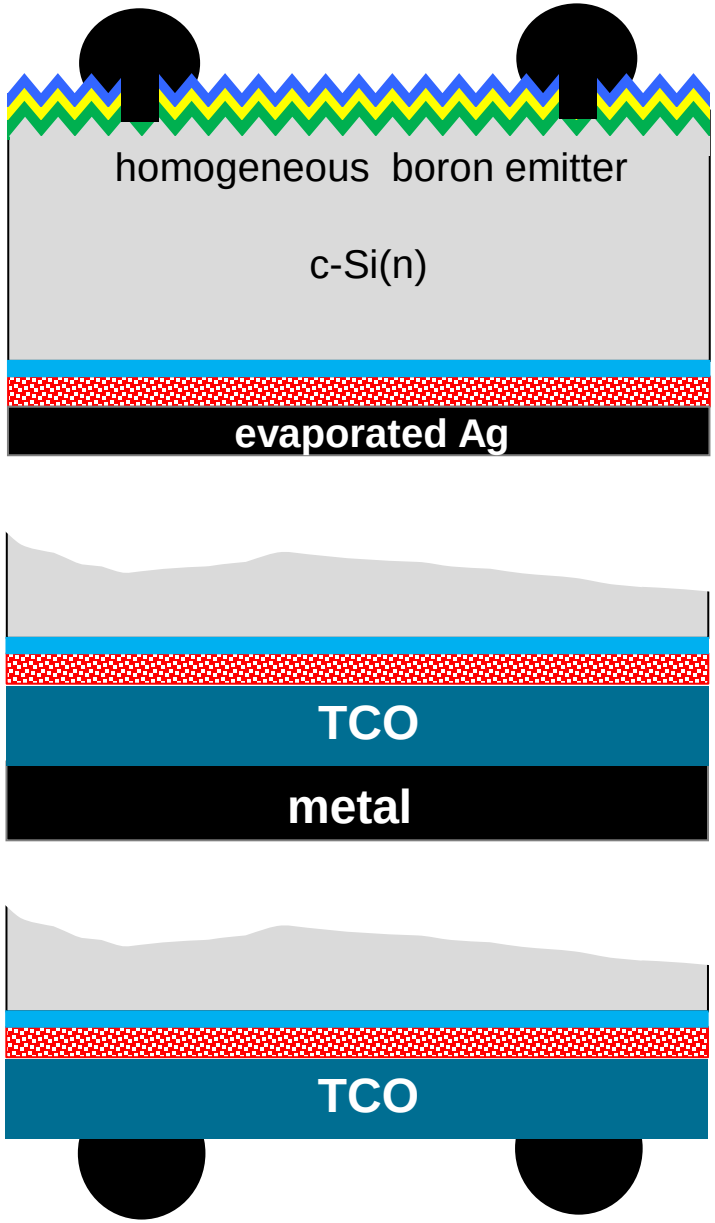
Non-Firing Approach
Current Work

- TCO / metal stacks

→ Similar to SHJ but >> 200°C



Summary

Amorphous Silicon Heterojunction ($T_{back\text{-}end} < 220°C$)

- Baseline screen printing process (η = 21.9%)
- Ink jet printing of nano-silver ink promising for multi-busbar / plating
- Novel laser transfer of seed layer + Cu plating (η = 22.2%)

TOPCon and poly-Si ($T_{back\text{-}end} > 220°C$)

- So far, $J_{0,met} >> J_{0,pass}$ for firing-through metallization
  - Only commercial Ag pastes investigated
  - Hence, lots of room for improvement for paste optimization
- Non-firing approach under evaluation
  - LCO + Cu-plating for high performance diffused front side
  - TCO + metal optimized for > 220°C

Acknowledgments

The authors would like to thank all colleagues at Fraunhofer ISE

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aufgrund eines Beschlusses des Deutschen Bundestages

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0324086A (HIPPO)

0325574 (Folmet)

0325825B (HERA)

0324125 (PV BAT 400)

and by

the EU's HORIZON 2020 programme for research, technological development and demonstration under grant agreement no. 727529 (PROJECT DISC)

Thank You Very Much for Your Attention!

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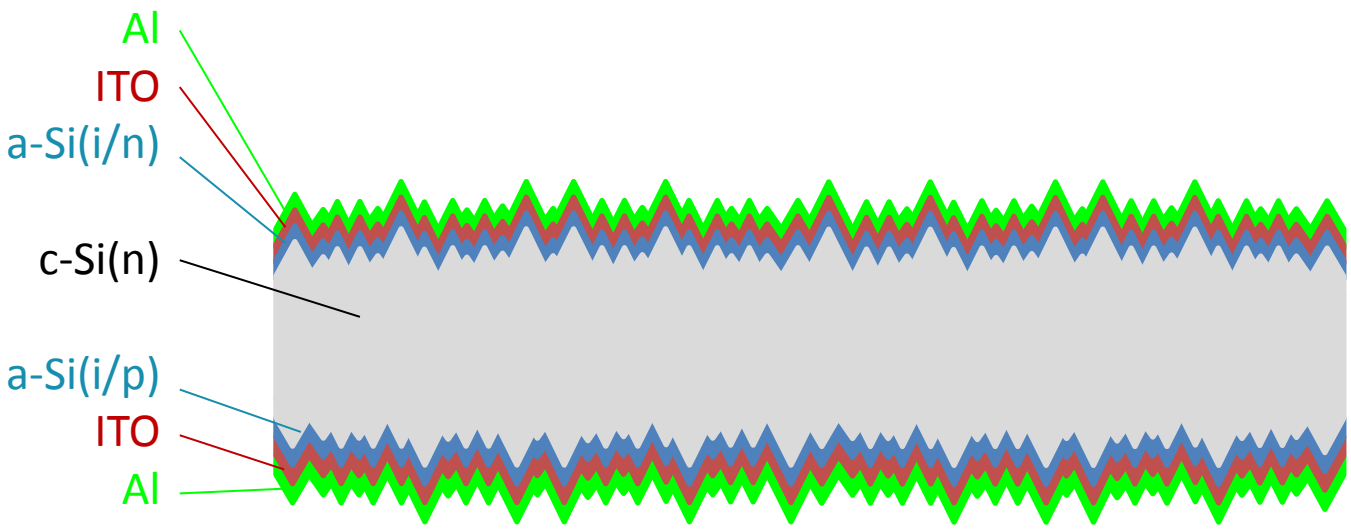
Approach 2: Selective plating using conductive mask

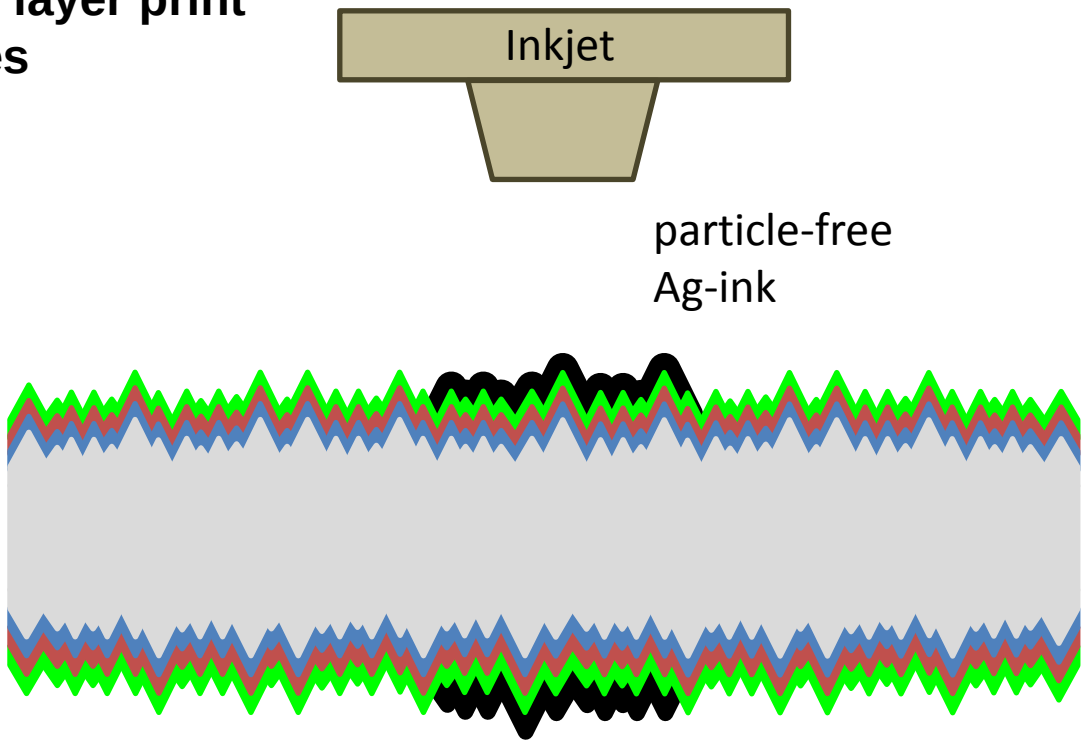
Precursor:



M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

Approach 2: Selective plating using conductive mask

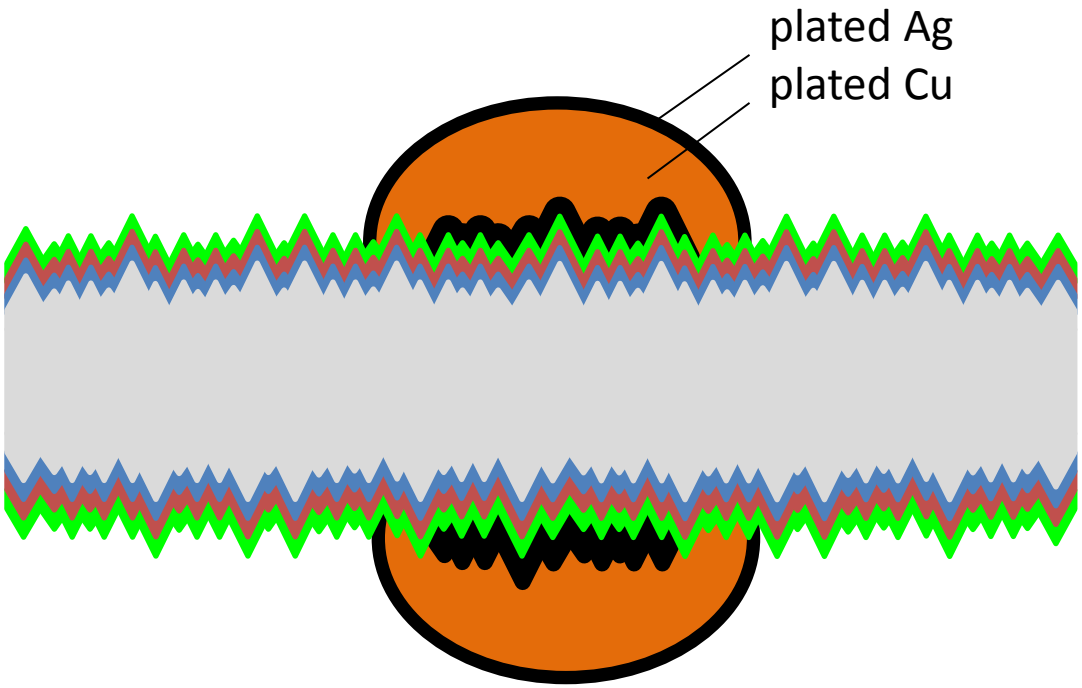
Step 1: seed layer print on both sides



M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

Approach 2: Selective plating using conductive mask

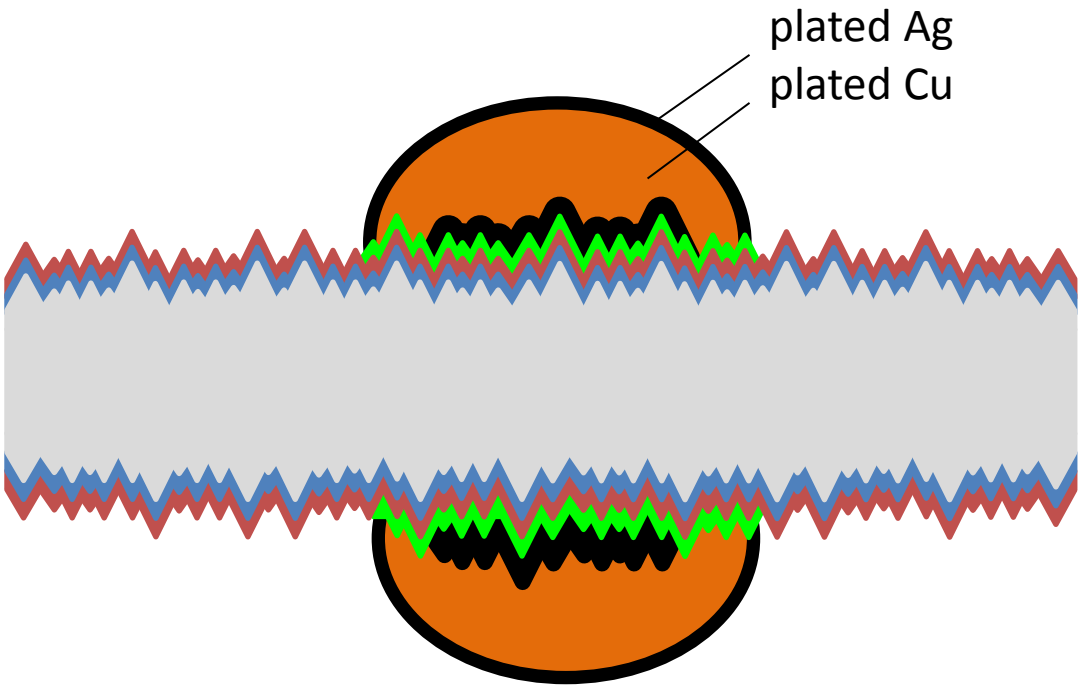
Step 2: simultaneous plating on both sides



M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

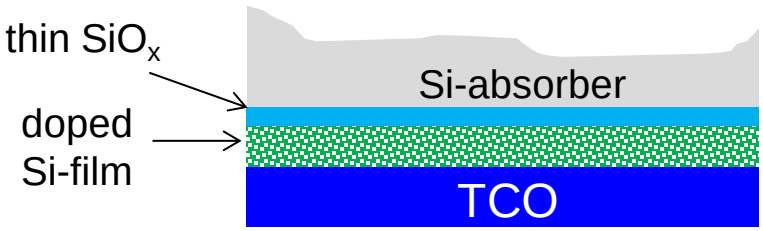
Approach 2: Selective plating using conductive mask

Step 3: etching of Al layers

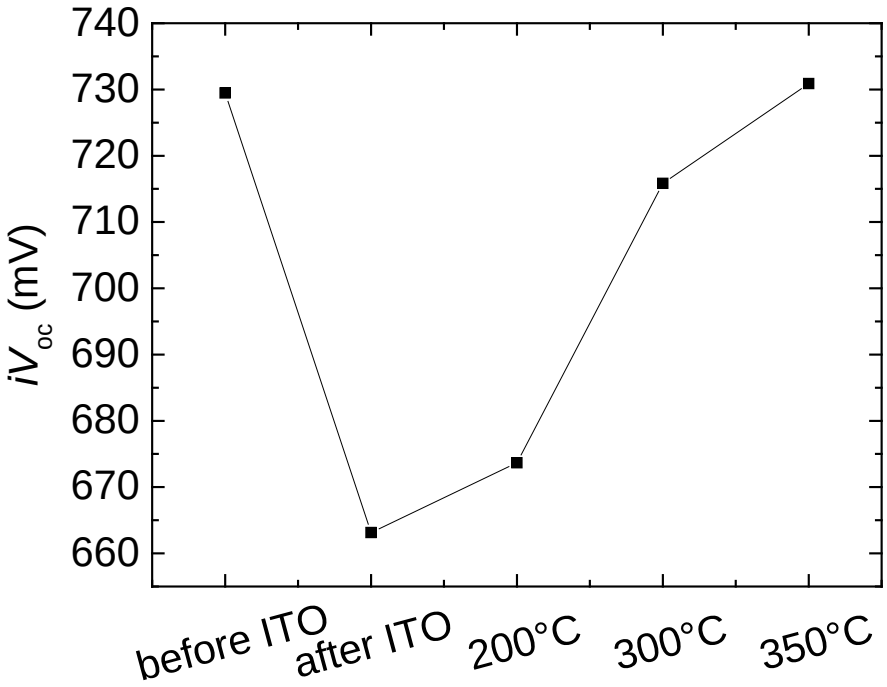


M. Glatthaar *et al.*, IEEE J-PV, 99, 1-5 (2017)

TOPCon
TCO Sputterdamage

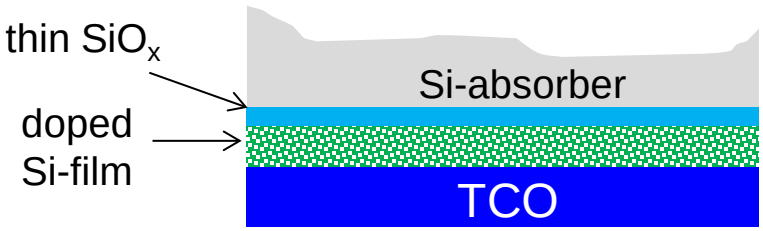


- > 200°C needed to cure damage

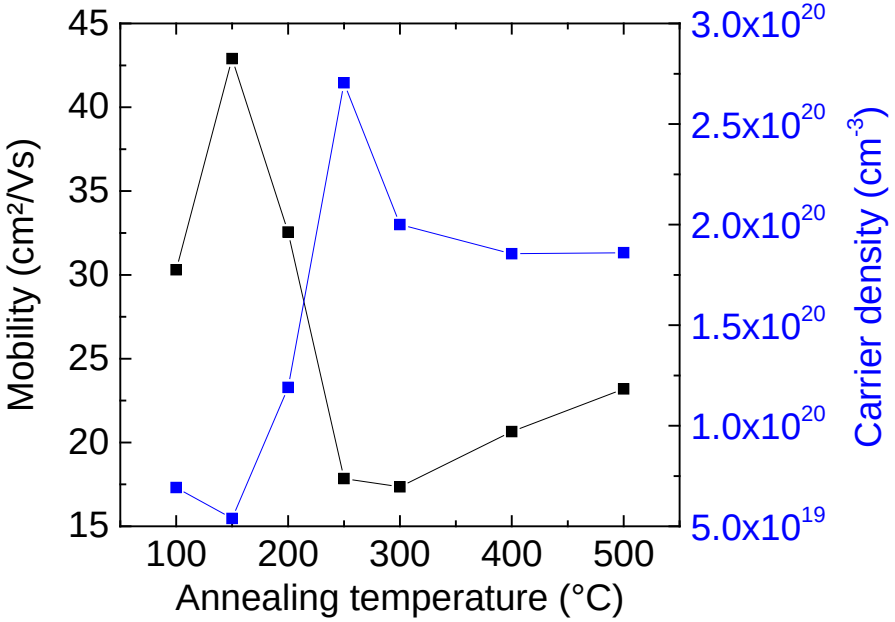


Fraunhofer ISE

TOPCon
TCO Sputterdamage



- > 200°C needed to cure damage
- > 200°C poor mobility
- → Trade-off passivation and TCO



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