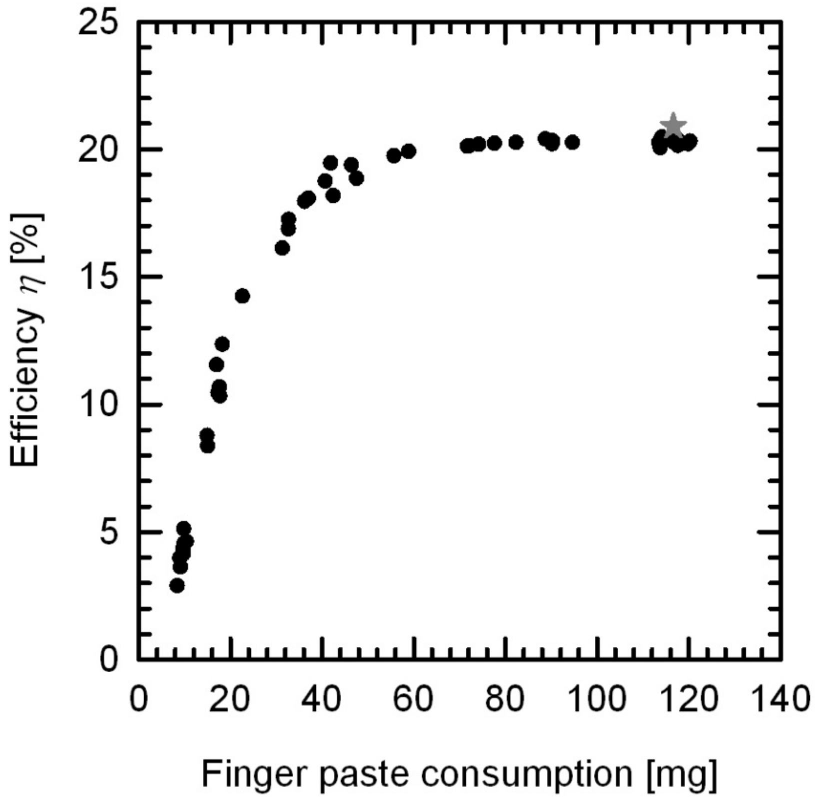
5th Metallization Workshop



Optimized stencil print for low Ag paste consumption and high conversion efficiencies

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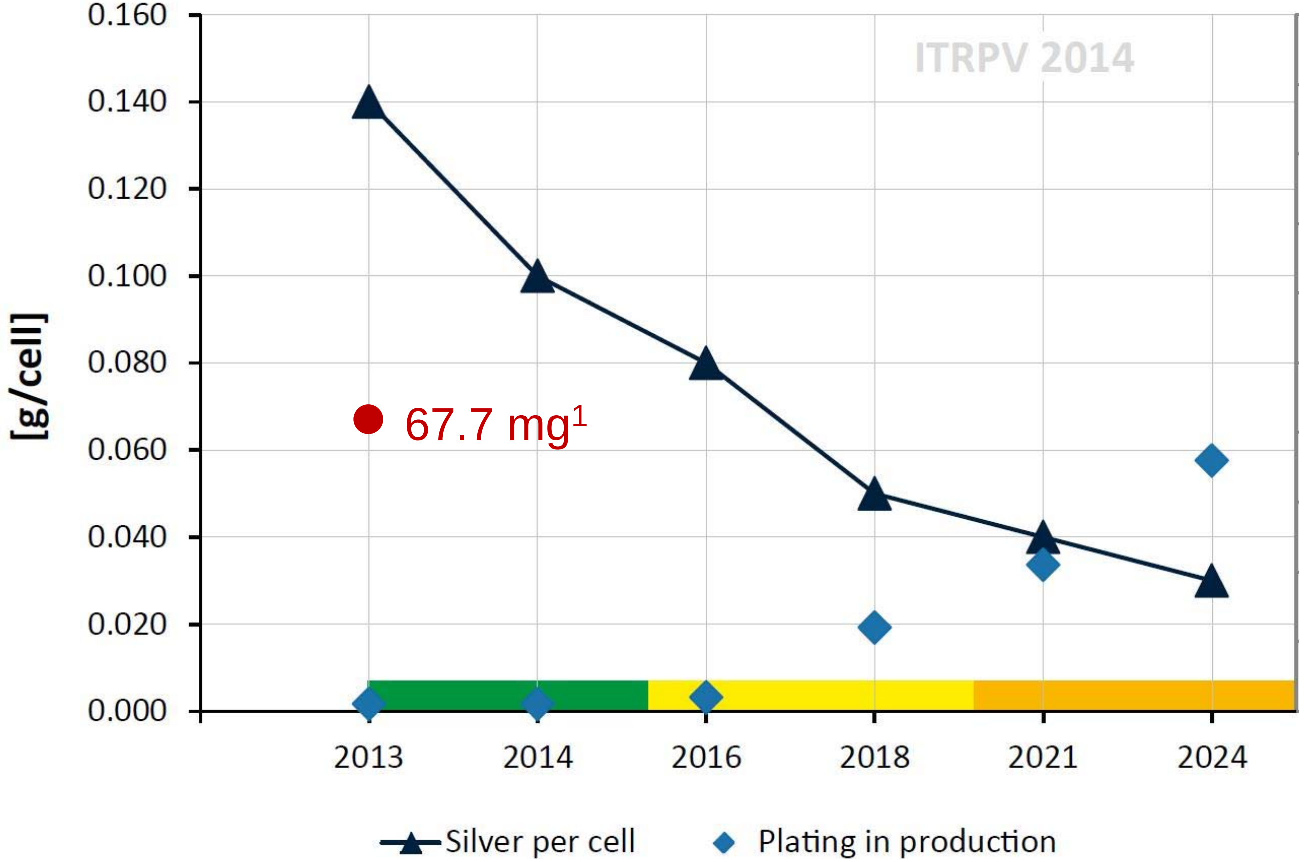
Institute for Solar Energy Research Hamelin

Motivation



- Cost factor for cell processing: Silver pastes
- Further improvement of screen printing: dual print
- Very low silver paste consumption reported with dual print

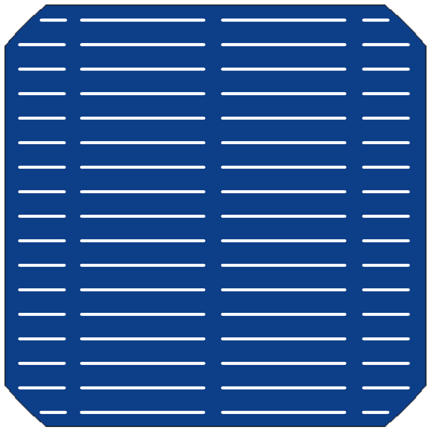
ITRPV Working Group, "International Technology Roadmap for Photovoltaic, 2013 Results"
[1]H. Hannebauer et al., *Proc 4th Metallization Workshop, Energy Procedia* **43**, (2013), p. 66-71

Dual print technique

Dual Print

1st print: Screen

2nd print: Stencil



Printing parameters:

- Stencil aperture: 40 µm
- Standard rectangular shaped 3 busbar
- Used squeegees:
  - Shore hardness 75A
  - Shore hardness 80A
  - Shore hardness 95A
  - Metal
- Printing pressure: 2.5 kg – 6 kg
- Snap off and printing speed is kept constant

(Used squeegees and printing pressure:) Different finger height/ finger paste consumption

Varying the paste consumption

Shore hardness 75A + 3 kg printing pressure

Shore hardness 95A + 5 kg printing pressure

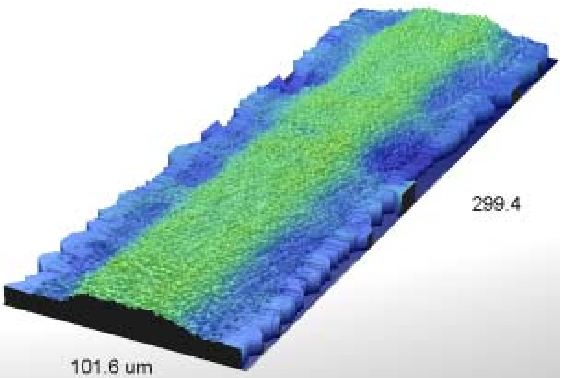
Metal squeegee + 5 kg printing pressure

More silver paste in the stencil opening →

Finger profiles

Shore hardness 75A

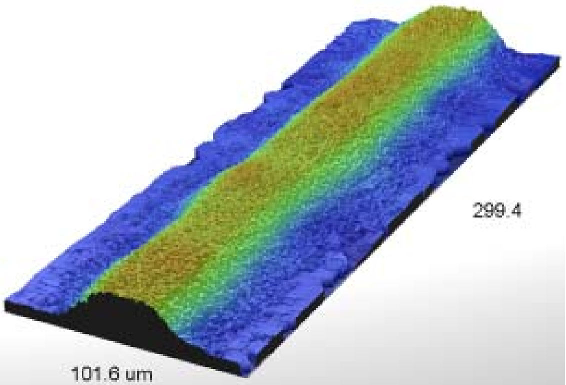
Avg height= 5.9 µm



Avg finger width: 55 µm

Shore hardness 95A

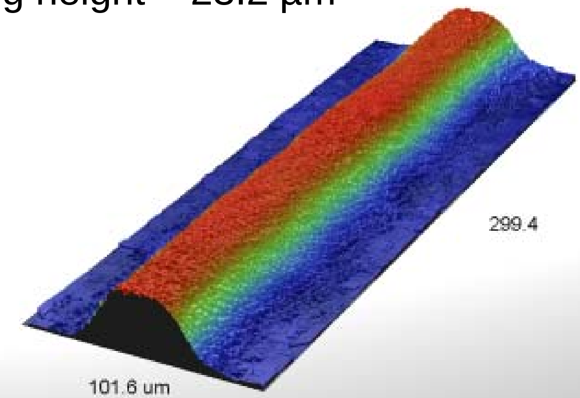
Avg height = 12.6 µm



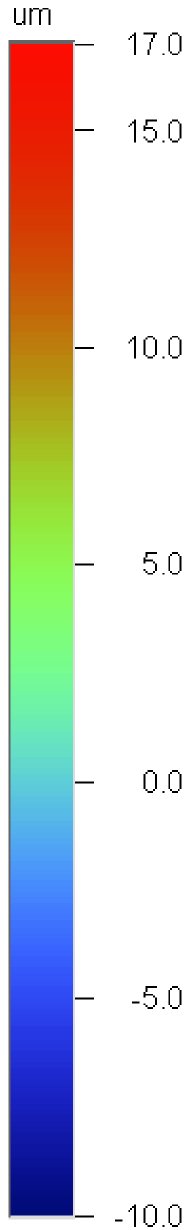
Avg finger width: 55 µm

Metal squeegee

Avg height = 23.2 µm

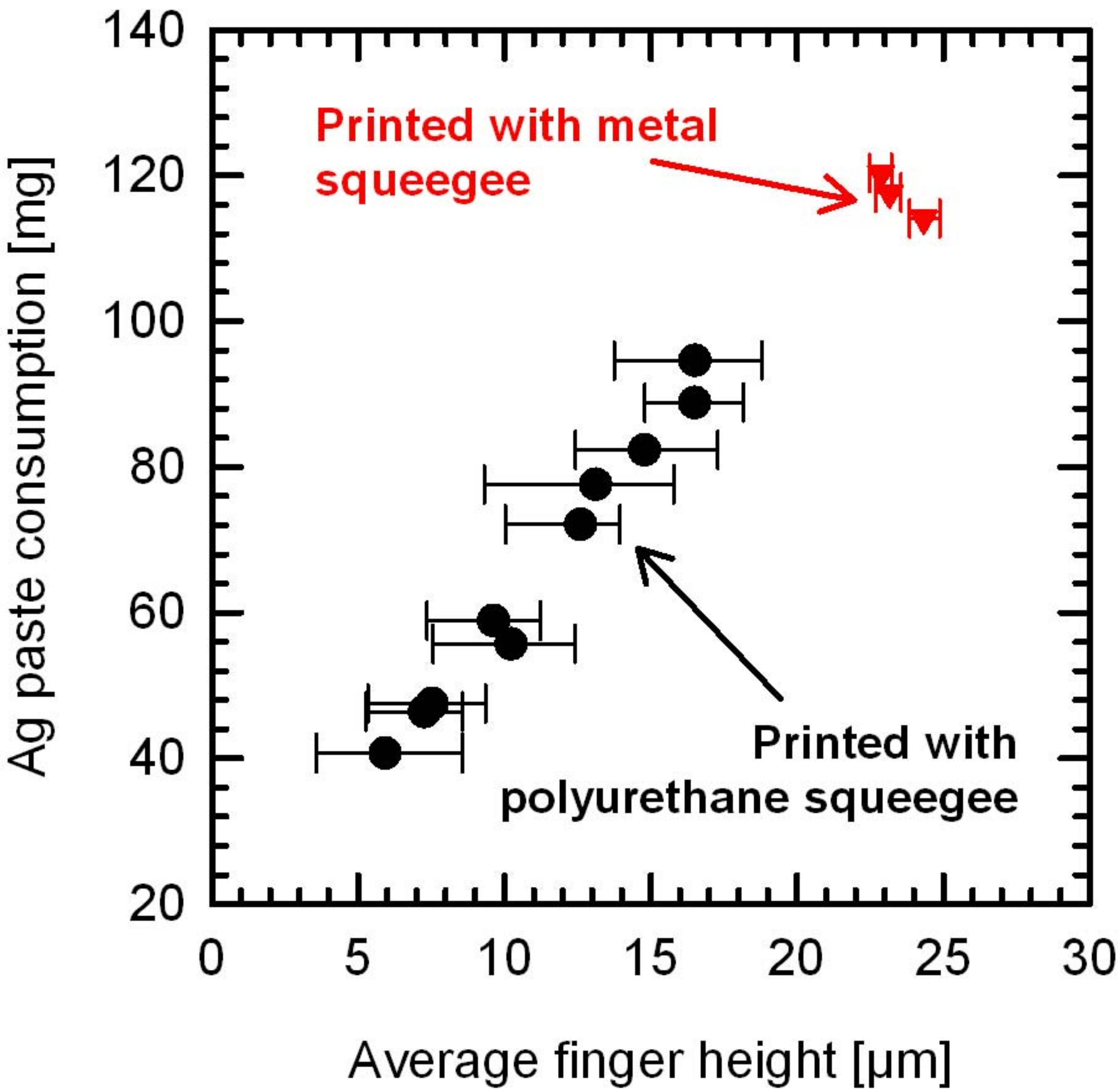


Avg finger width: 65 µm

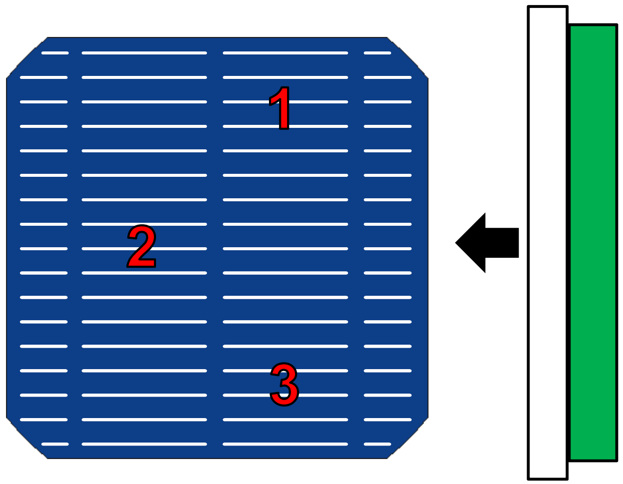


Nearly uniform finger height along the finger length

Dependence of finger paste consumption on finger height



- Error bars show min./max. of average finger heights at three measurement positions



- Very uniform distribution of finger heights across the cell with metal squeegee

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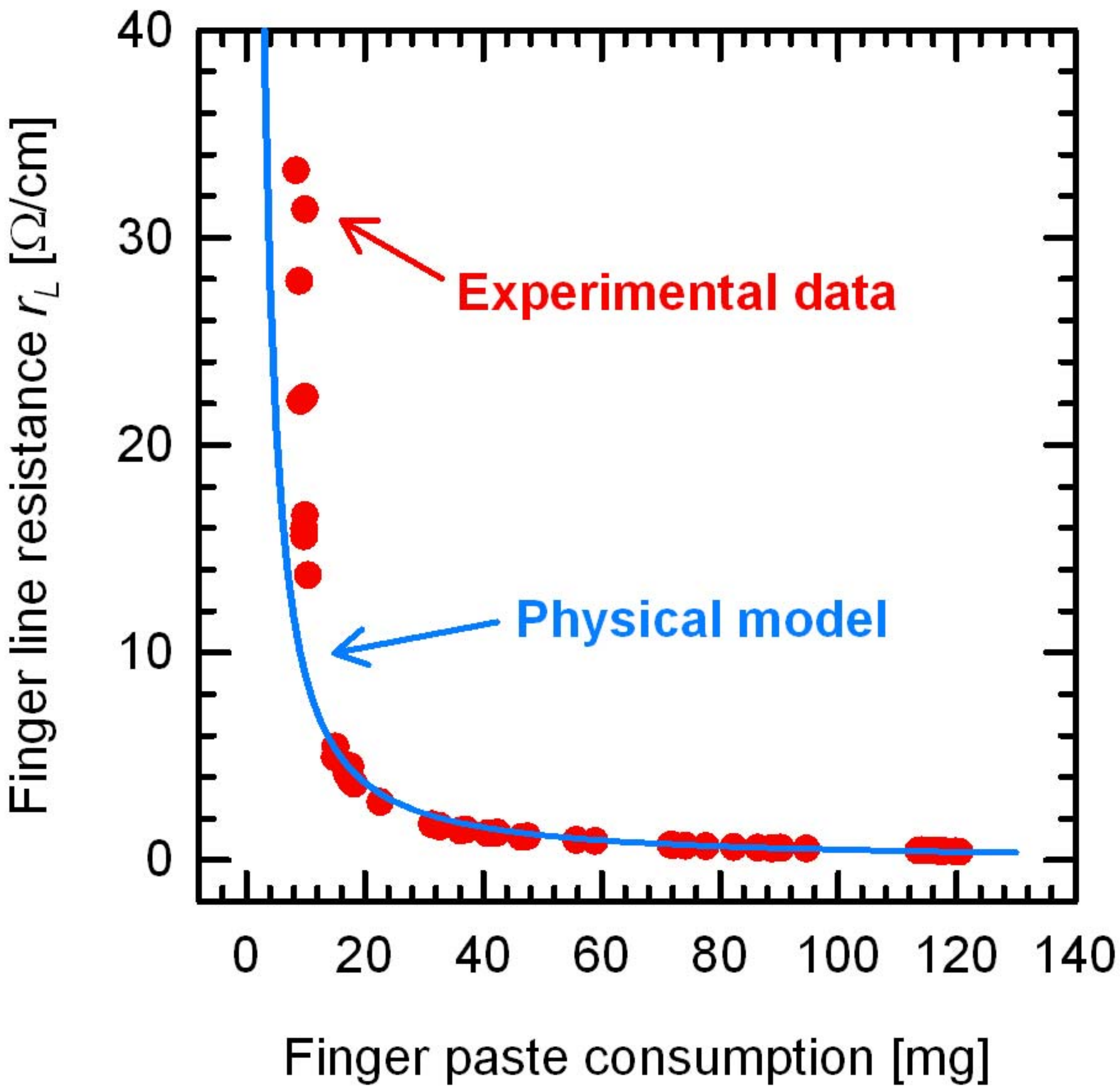
Finger line resistance

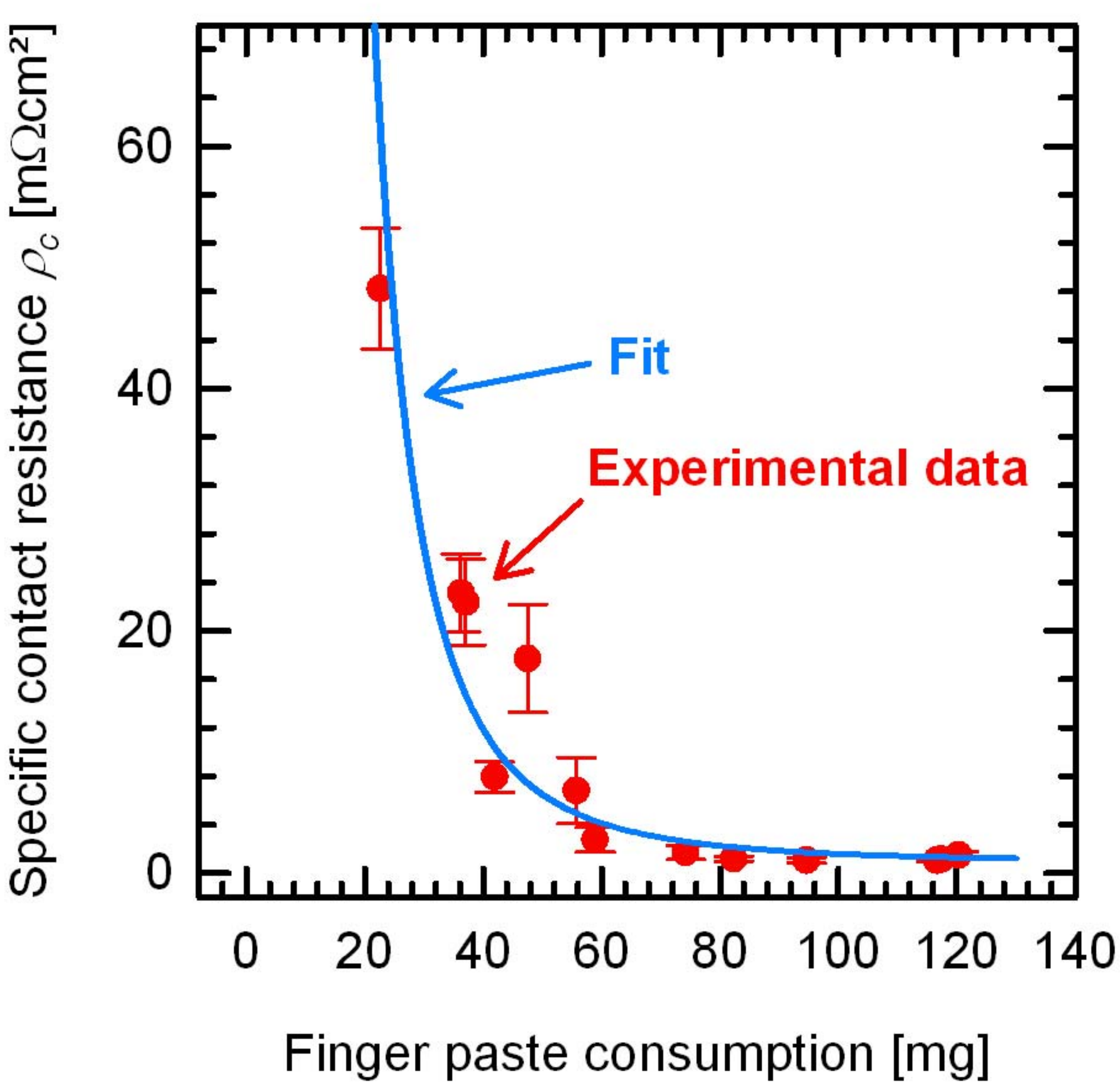


- Physical model for finger line resistance r_L:

$$r_L = \frac{\rho_{paste}}{A_{finger}}$$

- A_{finger} calculated with trapezoidal shaped finger
- ρ_{paste} = 4 µOhm*cm

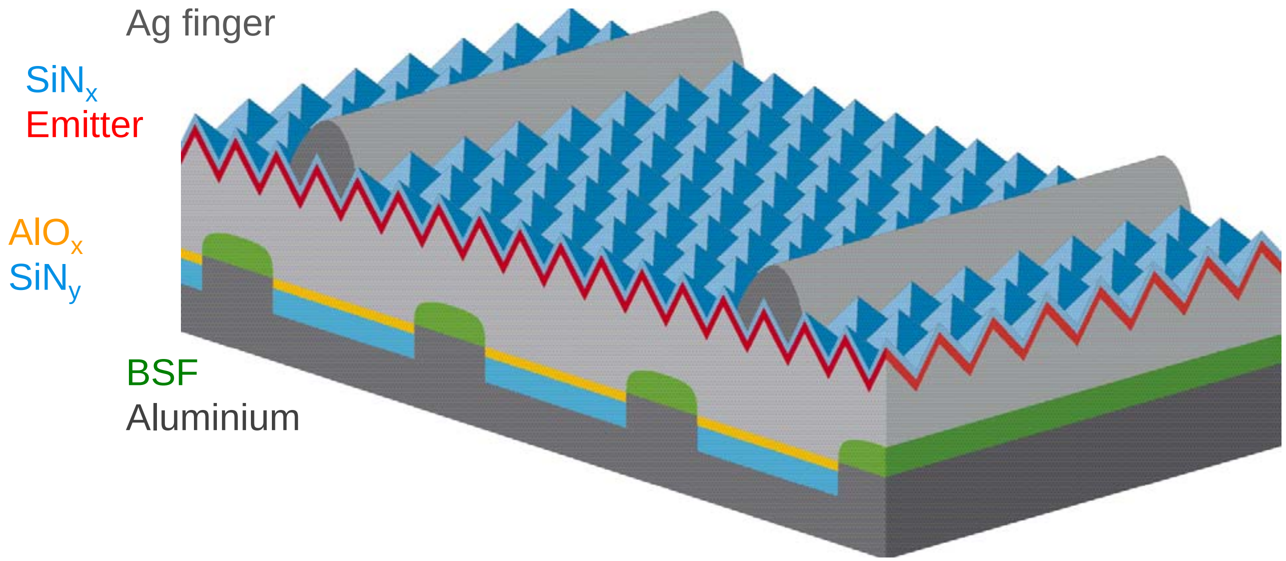
Specific contact resistance



- Mathematical power function used to fit the specific contact resistance ρ_c values
- Dependence of ρ_c on paste consumption and finger height is unexpected

PERC solar cell process

- Wafer cleaning
- Rear protection layer
- Texturing
- Phosphorus diffusion
- PSG + dielectric etch
- Rear: AlO_x/SiN_y
- Front: PECVD-SiN_x
- LCO at the rear
- Ag dual print
- Al screen-printing
- Co-firing



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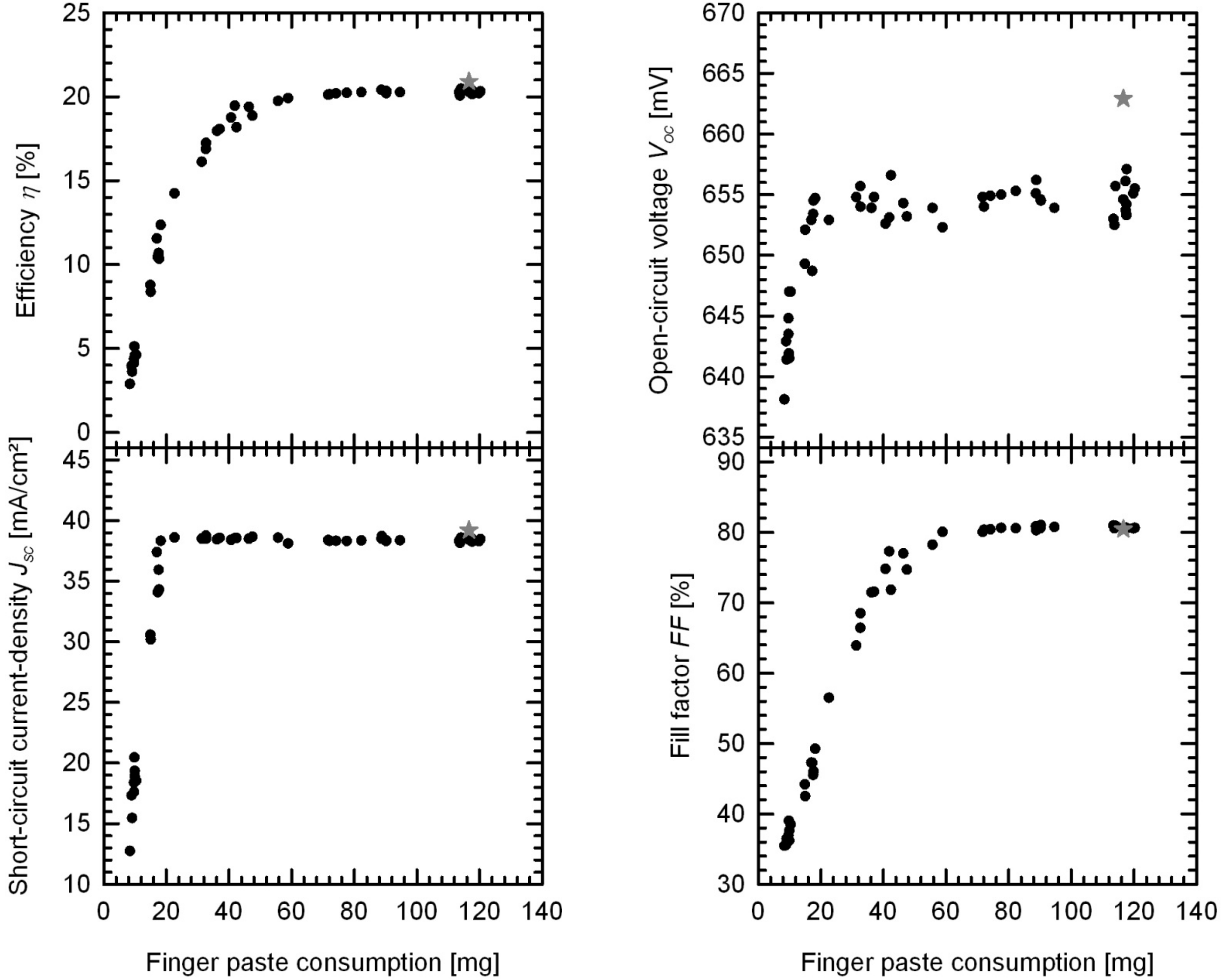
PERC solar cell results



☆ = 20.9% efficiency with improved emitter process

Analytical modelling

- Total resistance:

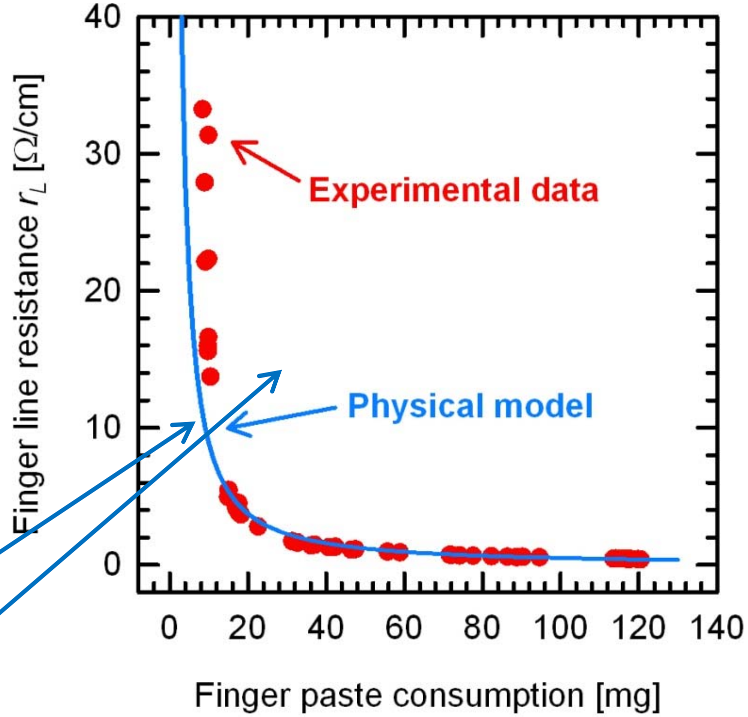
$$R_s = R_{finger} + R_{contact} + R_{emitter} + R_{base} + R_{rear}$$

- Finger resistance:

$$R_{finger} = \tfrac{2}{3} \cdot r_L \cdot l_f \cdot A_{uc}$$

- Contact resistance:

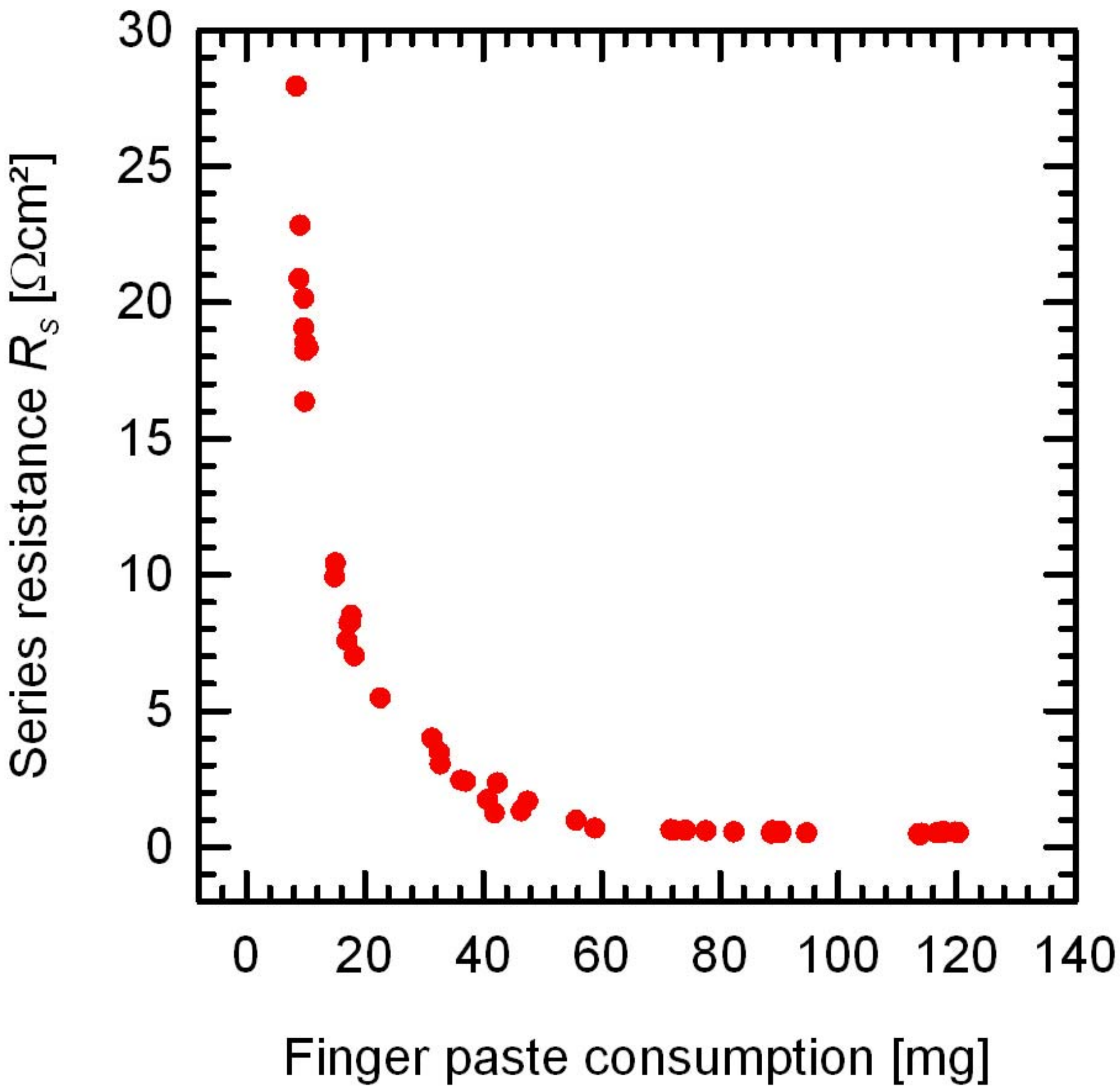
$$R_{contact} = \frac{\sqrt{R_{sheet}\rho_c}}{l_f} \coth\left(\frac{w_f}{2}\sqrt{\frac{R_{sheet}}{\rho_c}}\right) \cdot A_{uc}$$



- Assuming constant values for $R_{emitter}$, R_{base}, and R_{rear} and use fitted curves for r_L and ρ_c values

A. Mette, *PhD Thesis, Freiburg, Germany (2007)*

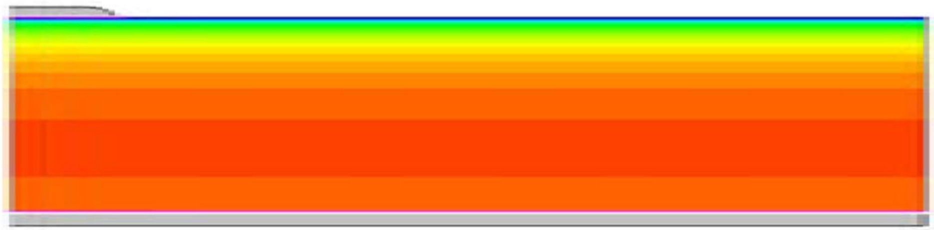
Modelling of series resistance



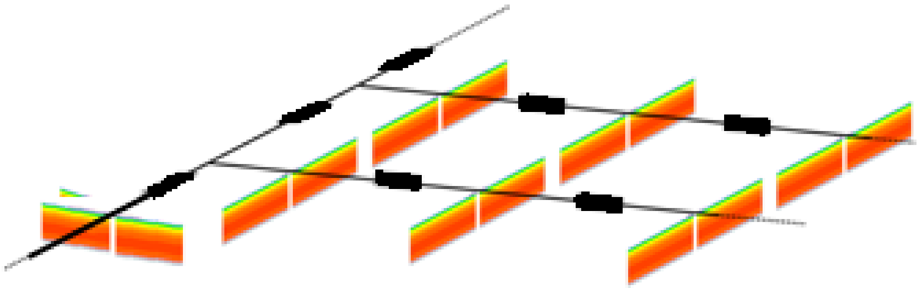
Good accordance for more than 40 mg finger paste consumption

Simulations of optimized finger profiles

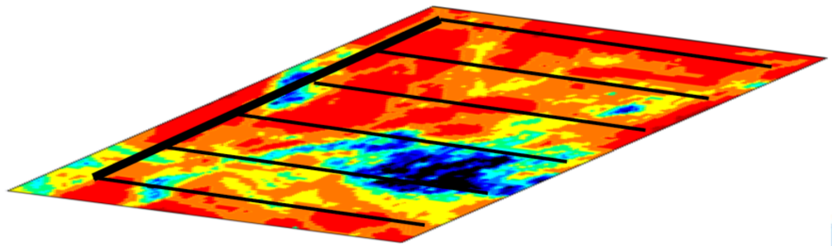
Semiconductor device simulation (Sentaurus)



Circuit simulation (SPICE)

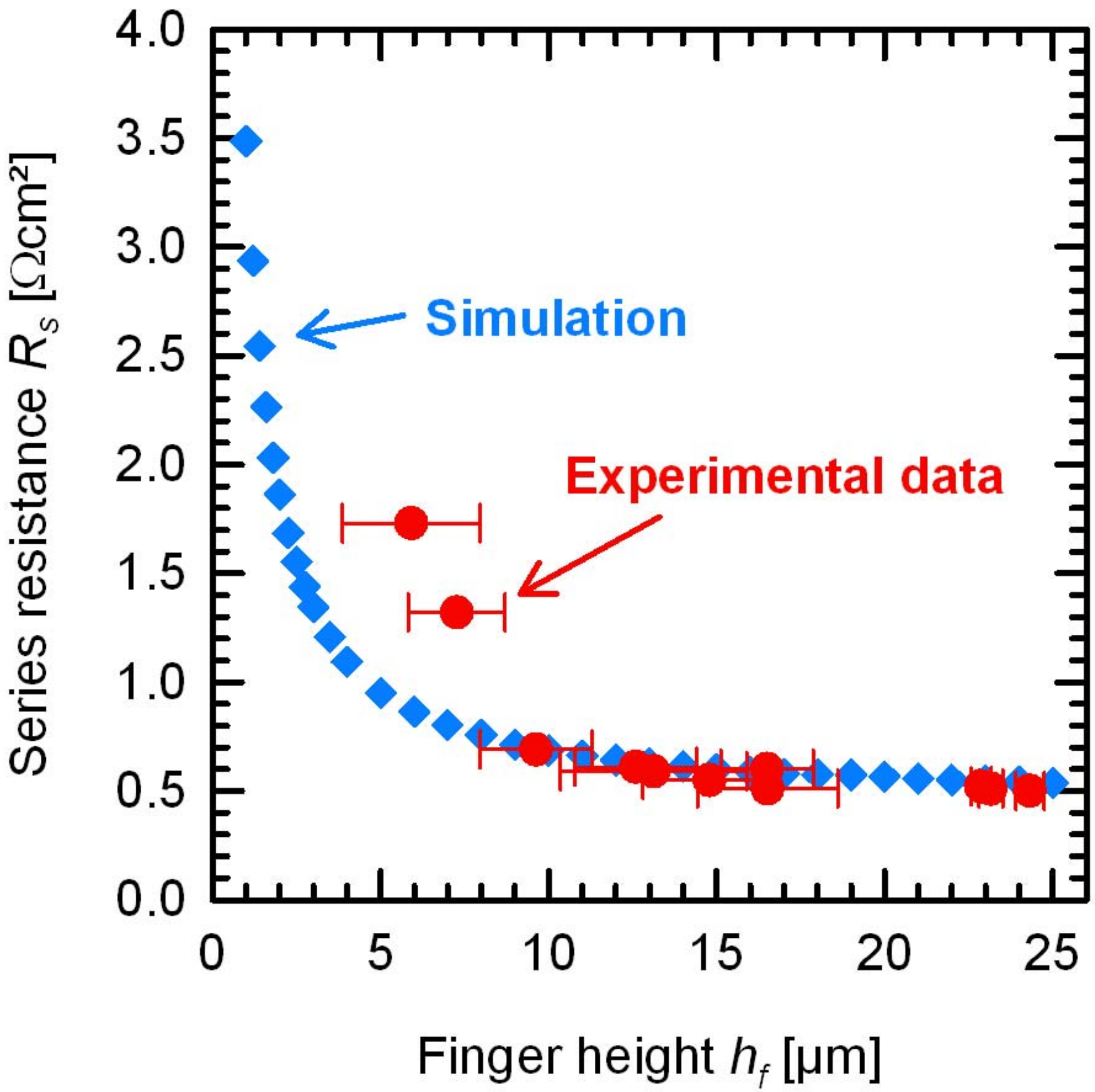


Solar cell simulation



P. P. Altermatt et al, *Proc 24th EUPVSEC,* Hamburg, Germany (2009), p. 901-906

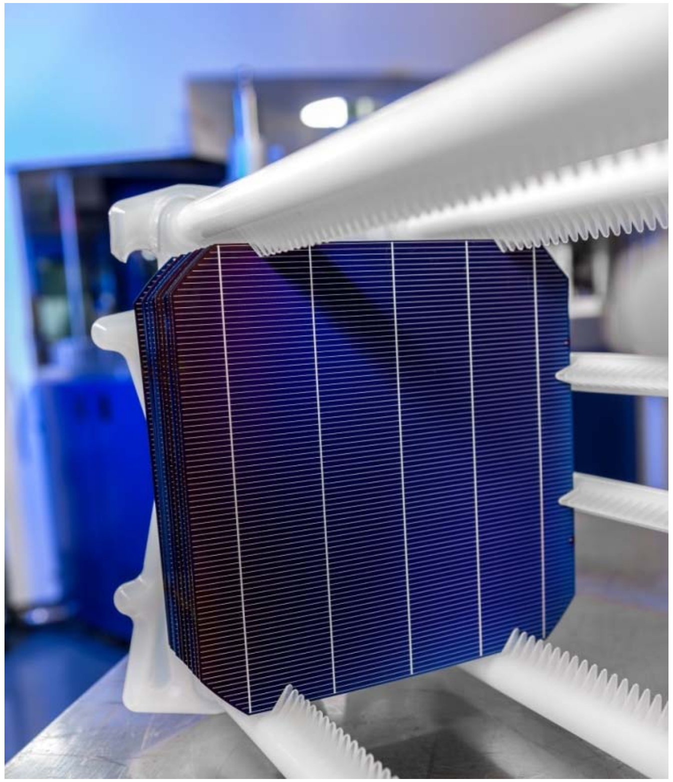
Simulation of series resistance



- Finger height is assumed to be perfectly uniform across the finger length and the cell
- Observed dependence of ρ_c on paste consumption is not include
- Low R_s for 5 µm finger height corresponds to 40 mg paste consumption

Outlook: Optimization of front side grid

Dual-printed record PERC efficiency of 21.2%* at ISFH[1]



* Independently confirmed by ISE CalLab.

- Smaller busbar pitch → more than 50% less cross-section area needed
- Less than 30 mg finger paste consumption for high cell efficiency
- Additional 2 mg reduced Ag paste consumption due to reduced busbar area

[1]H. Hannebauer et al., *Phys. Status Solidi RRL* **8** *(8),* (2014), p. 675-679

Summary

- High conversion efficiency of 20.9% with dual printed PERC solar cell achieved
- Average efficiency of 20.2% demonstrated with dual print for finger paste consumption down to 60 mg
- Simulations indicate possible further reduction of finger paste consumption down to 40 mg
- Potential of high cell efficiency with less than 30 mg finger paste consumption additionally applying 5 busbar front grid
- Root cause for dependence of ρ_c on paste consumption and finger height need further investigations

Acknowledgement

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