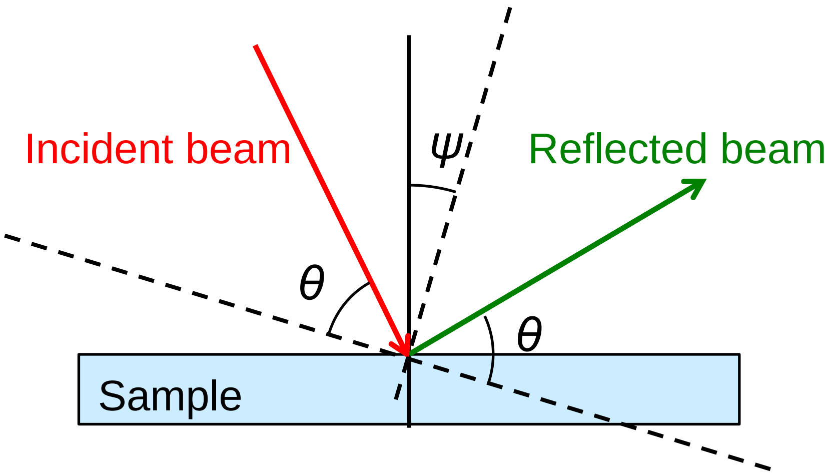
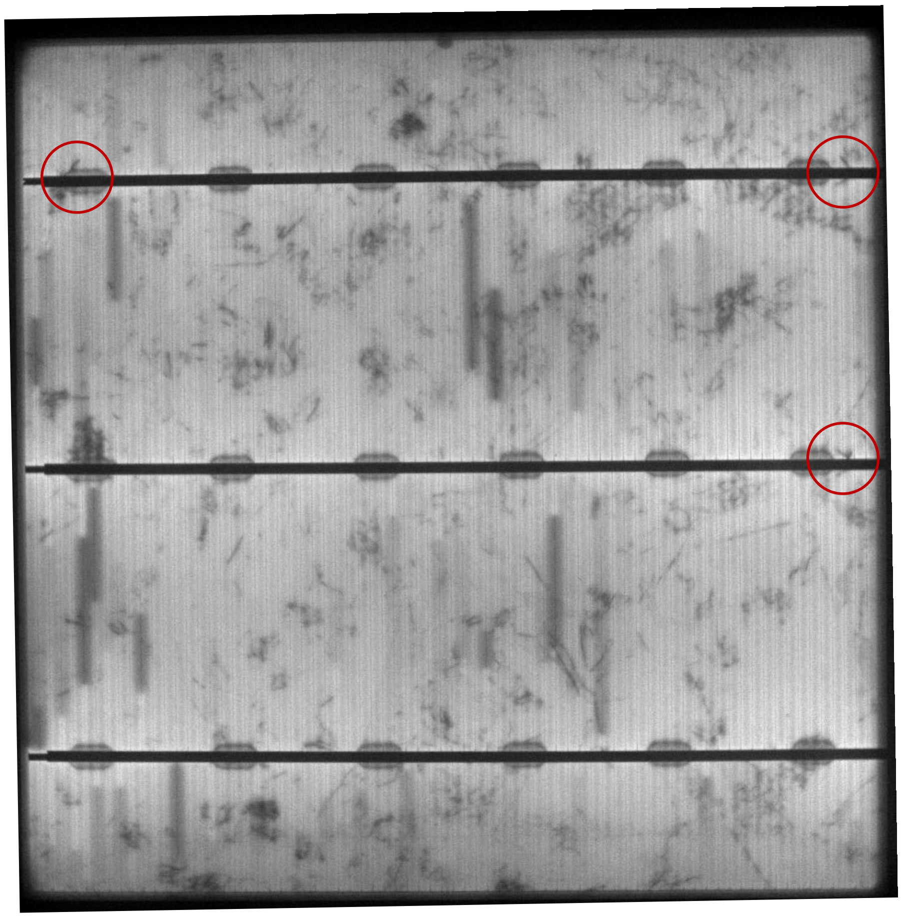


Stress measurements in Silicon solar cell interconnect ribbons using X-ray diffraction

A. Morlier, J. Käsewieter, F. Haase

Influence of cell interconnect ribbon stress on solar cell cracking?



- Cracks in solar cells lead to power losses by insulating parts of the cells[1,2]
- Cracks along the busbars and cell interconnect ribbons (CIR) potentially insulate a large area[1,2]

[1] M. Köntges, I. Kunze, S. Kajari-Schröder, X. Breitenmoser, B. Bjørneklett, Sol. Energy Mater. Sol. Cells, 95 (2011), p.1131

[2] M. Sander, S. Dietrich, M. Pander, M. Ebert, S. Thormann, J. Wendt, J. Bagdahn, 27th European Photovoltaic Solar Energy Conference Frankfurt, Germany (2012), p. 3188

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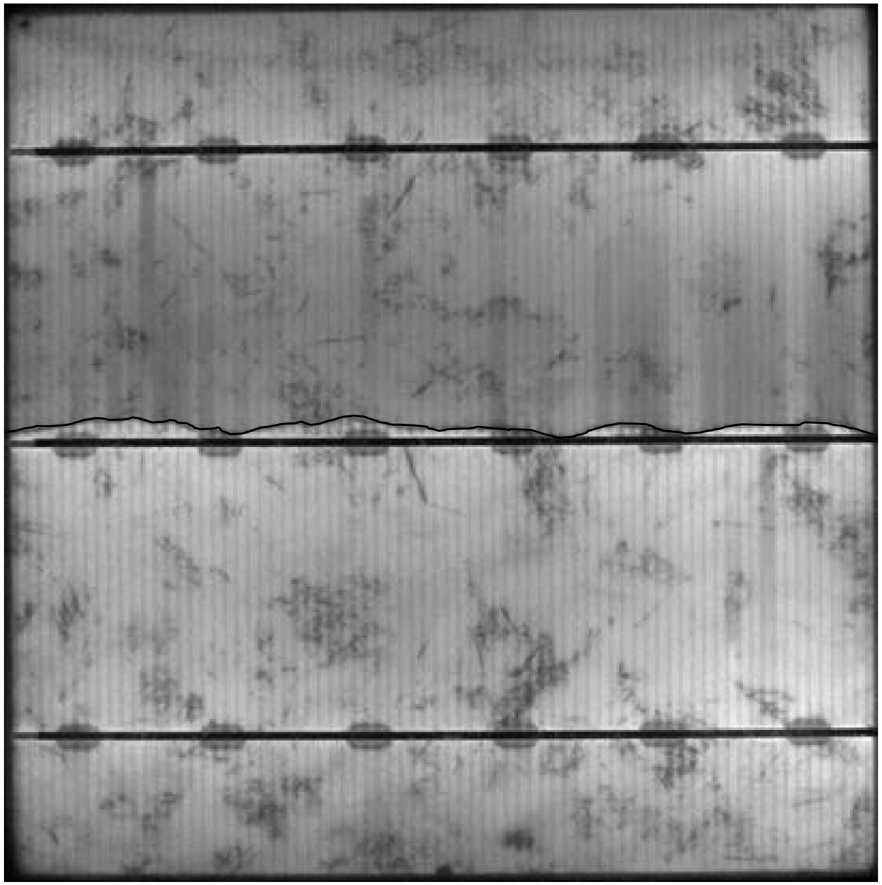

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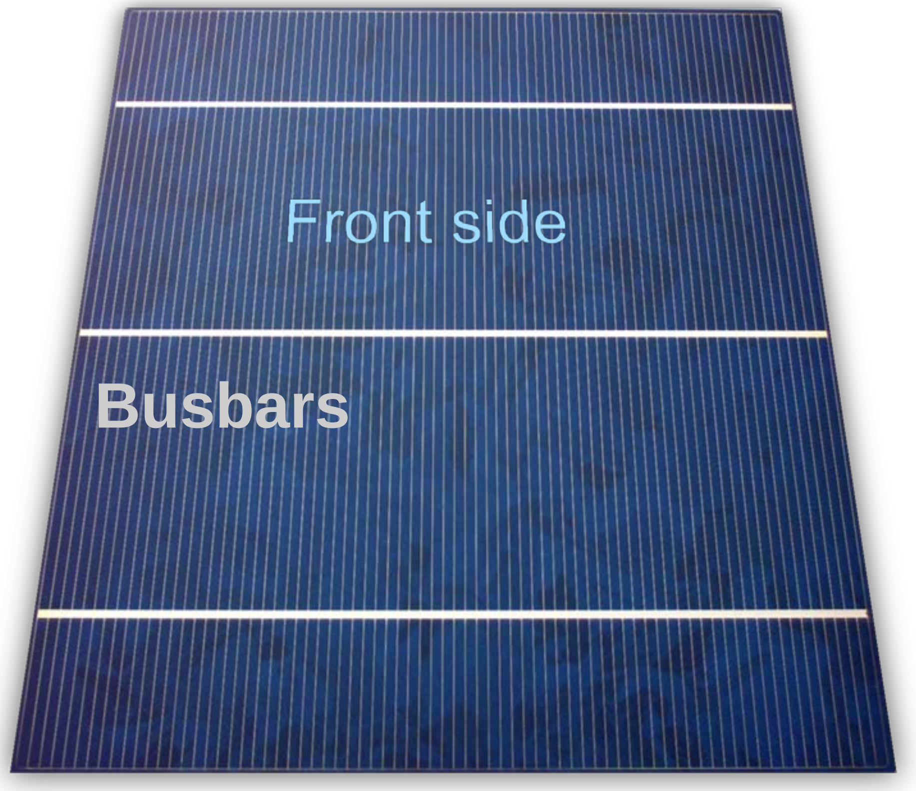
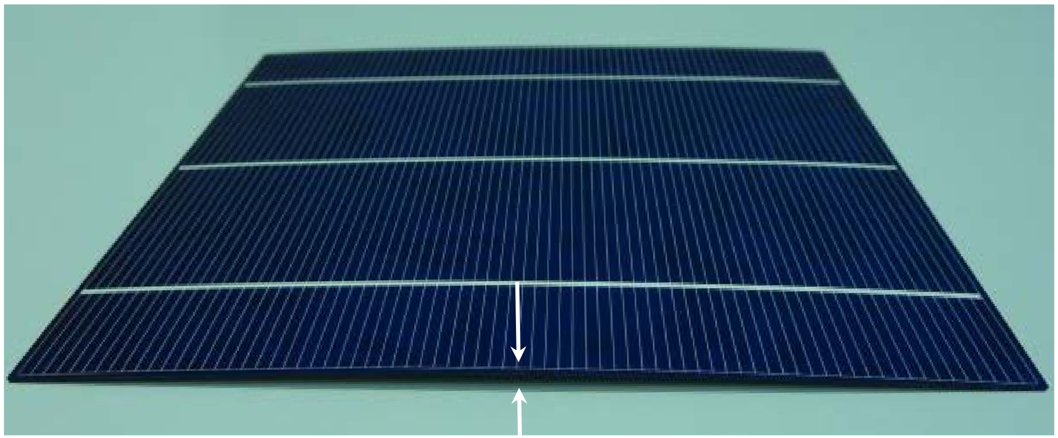
Standard screen printed solar cell



- 3 Ag busbars at front side as soldering contact

Standard screen printed solar cell

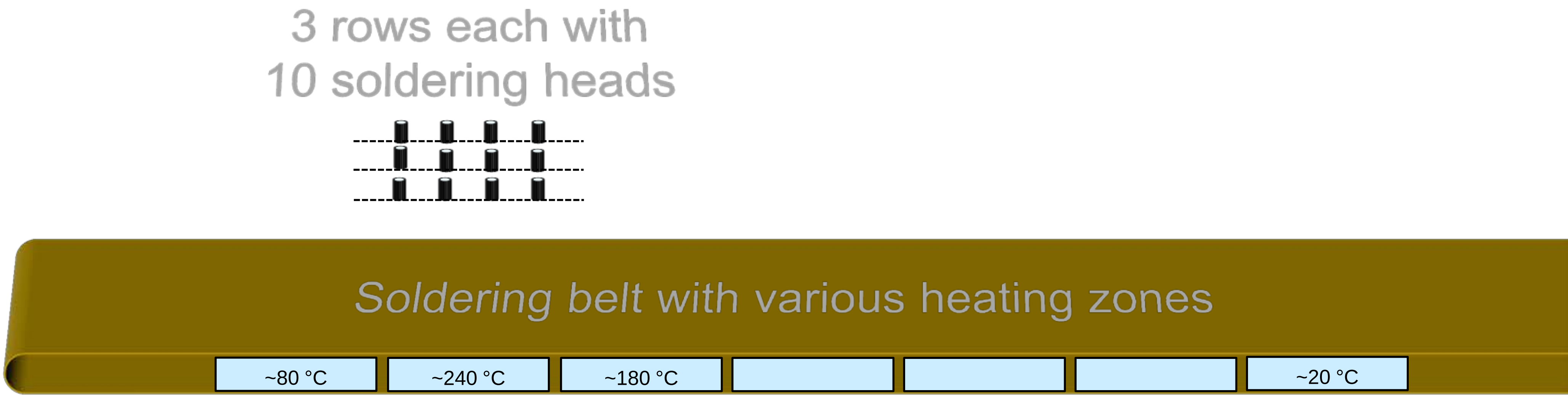


- 3 Ag busbars at front side as soldering contact
- Initial bow of about 2.1 mm

Standard screen printed solar cell

- 3 Ag busbars at front side as soldering contact
- Initial bow of about 2.1 mm
- 3 rows each with 6 silver pads at rear side as soldering contact

Soldering process



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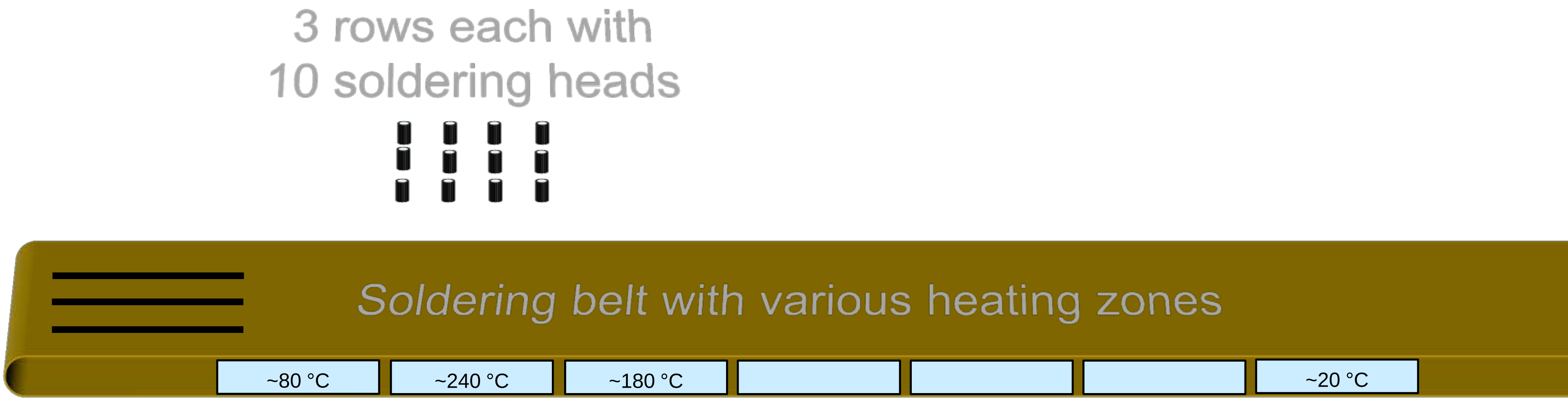
Soldering process

- CIR positioning



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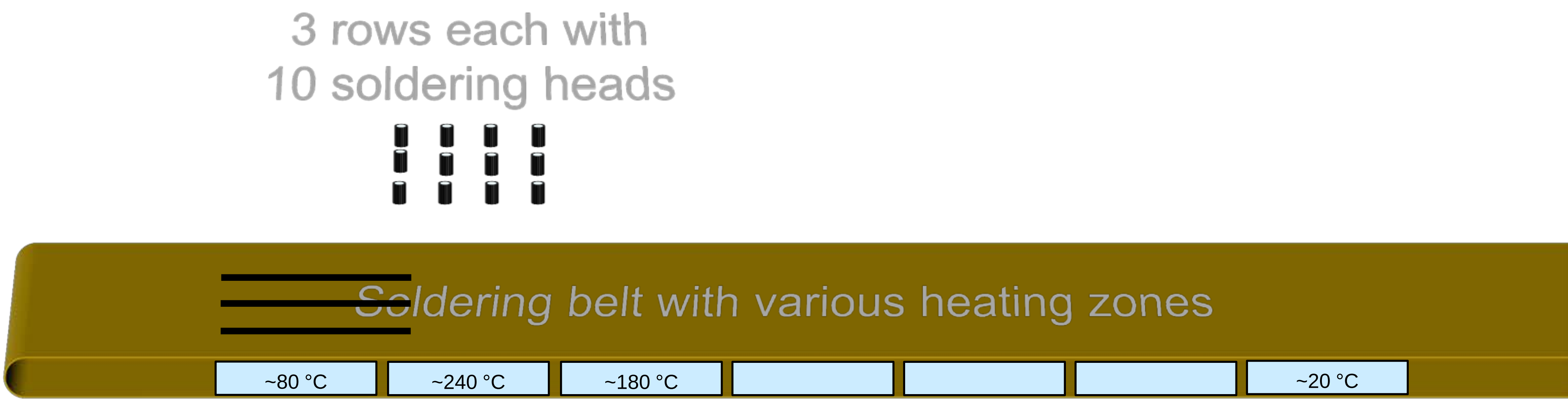
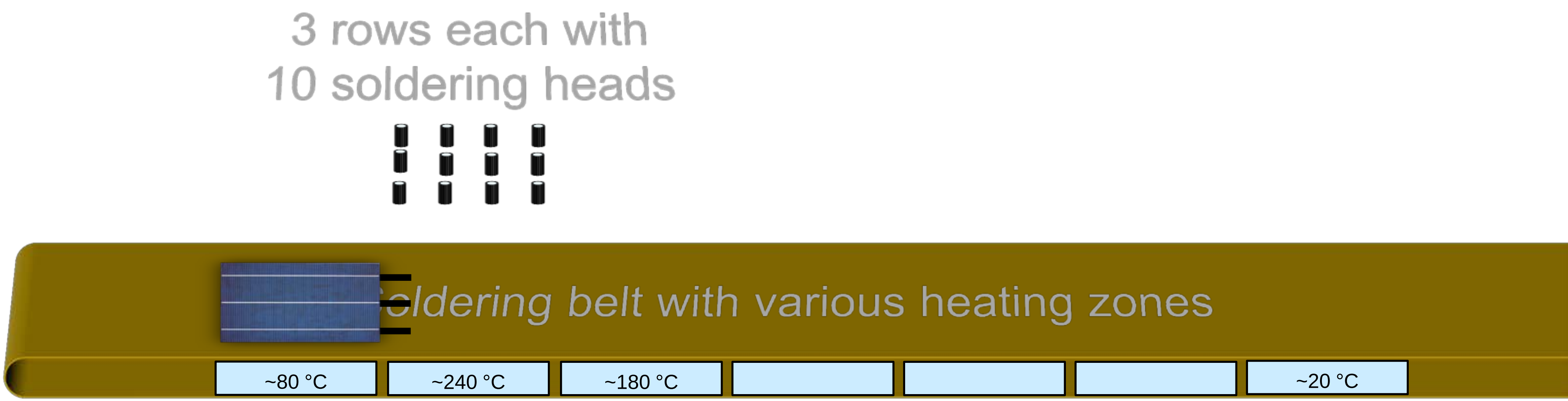
Soldering process

- CIR positioning
- Belt moving



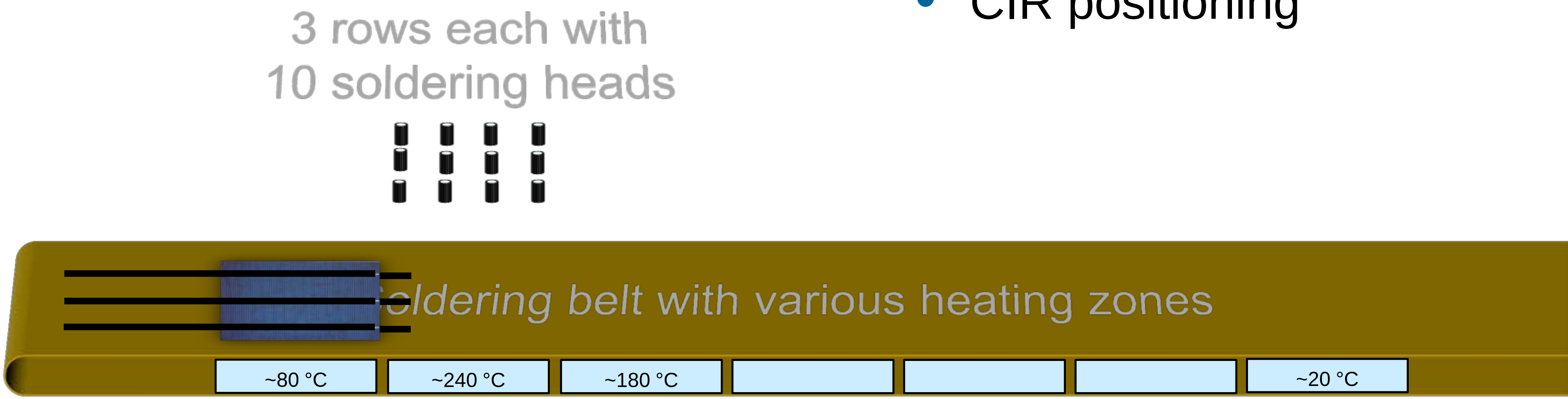
Soldering process

- CIR positioning
- Belt moving
- Solar cell positioning



Soldering process

- CIR positioning
- Belt moving
- Solar cell positioning
- CIR positioning



Soldering process

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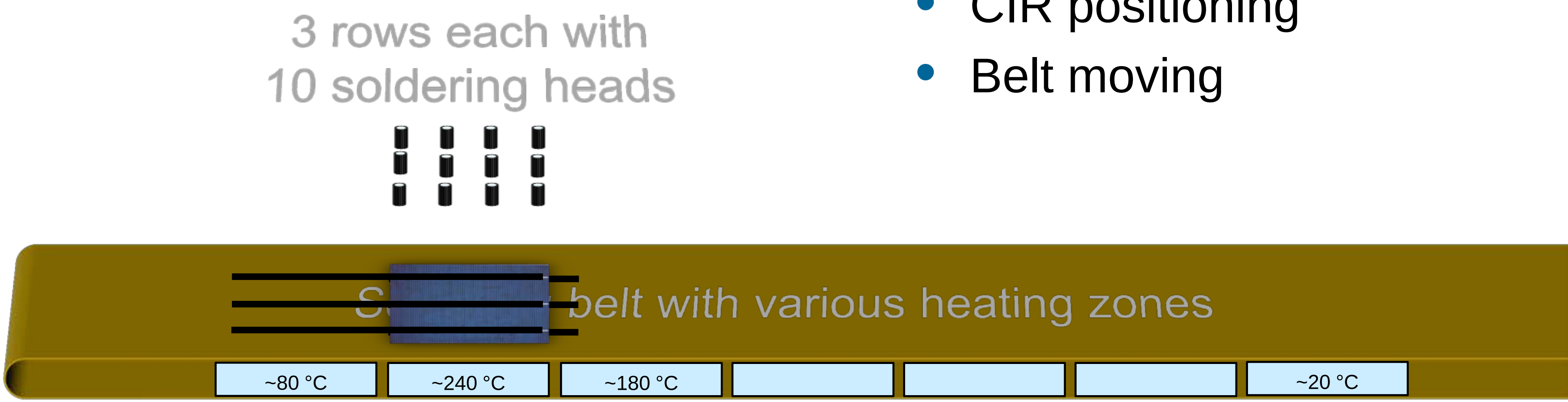


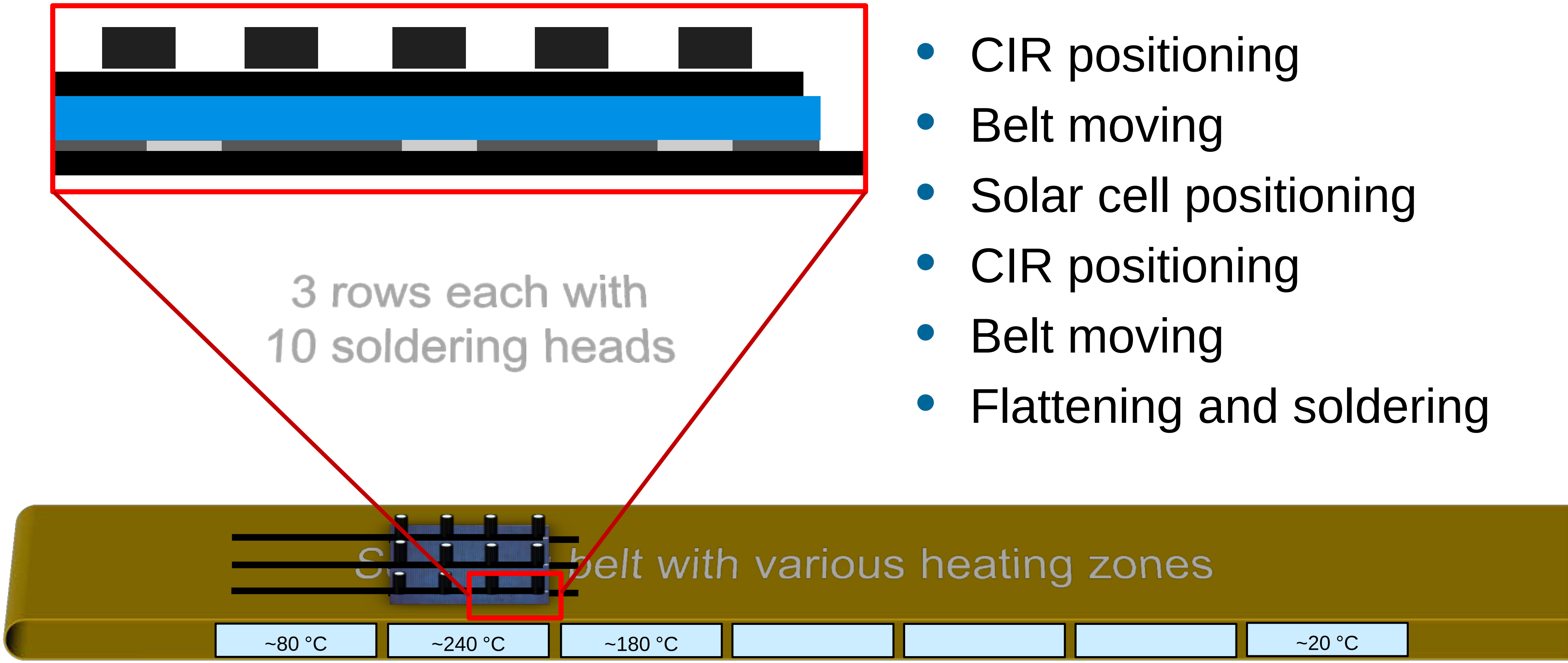
Soldering process

- CIR positioning
- Belt moving
- Solar cell positioning
- CIR positioning
- Belt moving
- Flattening and soldering

3 rows each with
10 soldering heads

Soldering process

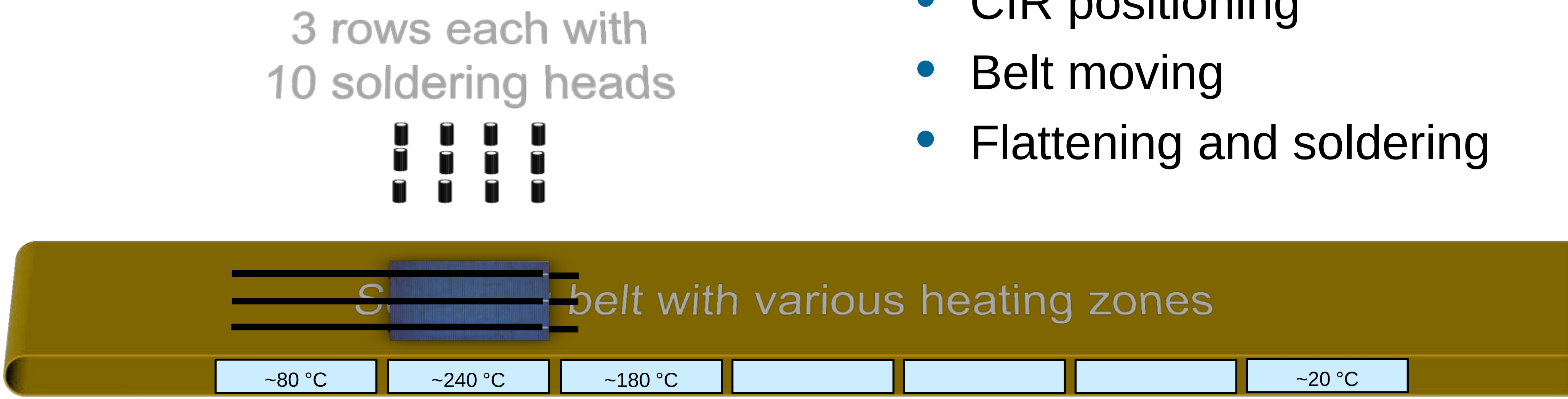
Cross section



- CIR positioning
- Belt moving
- Solar cell positioning
- CIR positioning
- Belt moving
- Flattening and soldering

Soldering process

- CIR positioning
- Belt moving
- Solar cell positioning
- CIR positioning
- Belt moving
- Flattening and soldering



Soldering process

- CIR positioning
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3 rows each with
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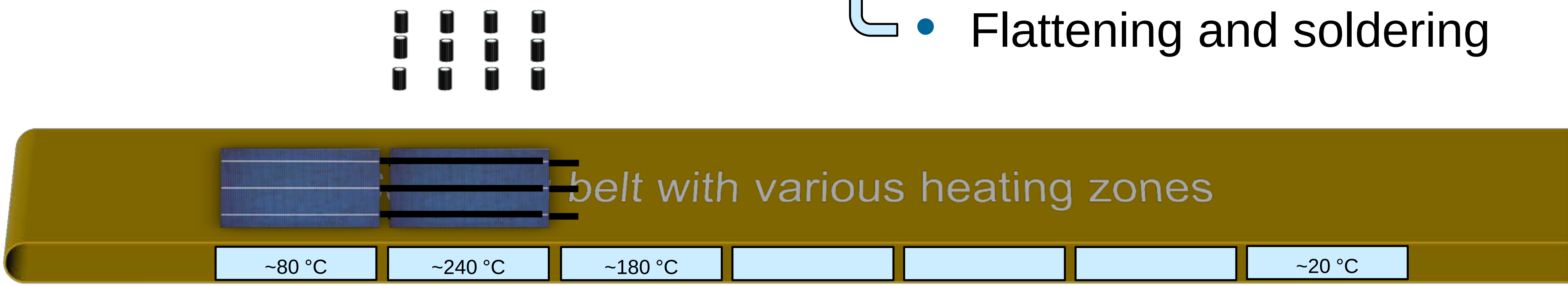
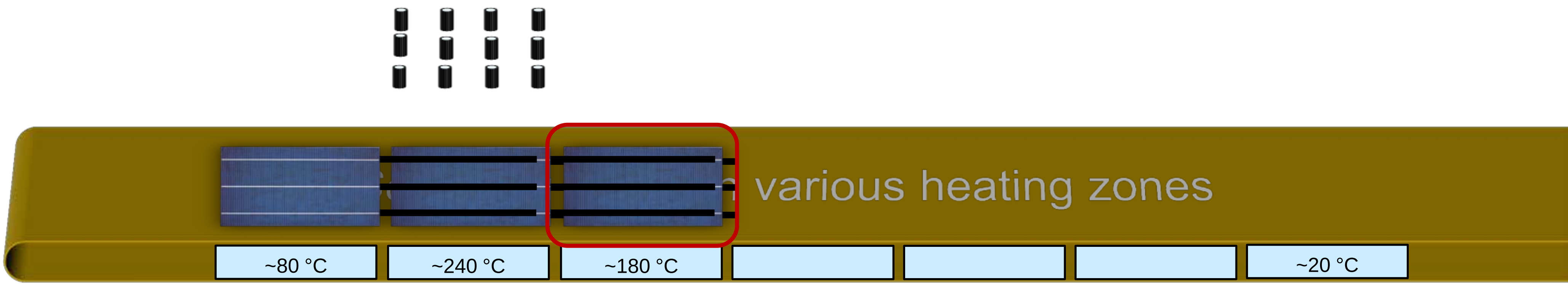


Stress estimation in CIR due to soldering process

- Solder solidifies at about 180 °C → CIR connects to initially bowed solar cell



Stress estimation in CIR due to soldering process

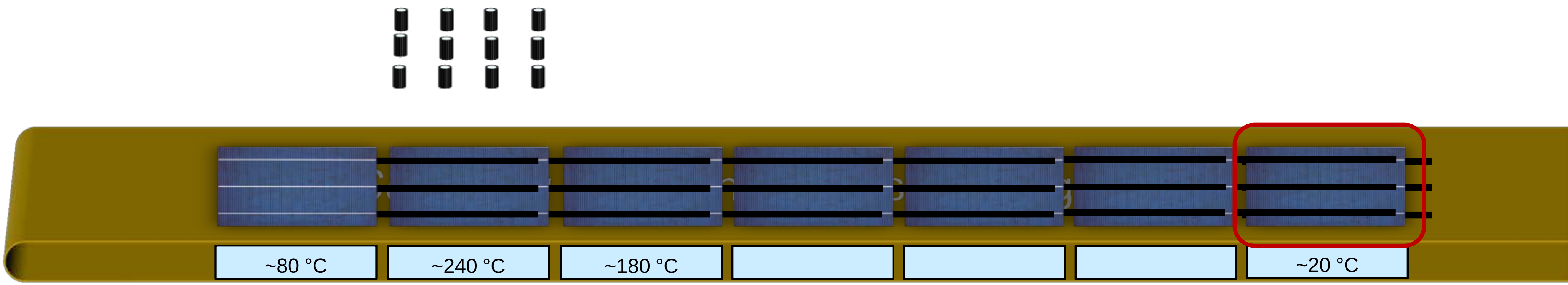
Assumptions:

1. Coefficients of thermal expansion [10^{-6} K^{-1}]
   $\alpha_{Cu} = 16.5$ $\alpha_{Si} = 2.6$ $(\alpha_{Cu} - \alpha_{Si}) = 13.9$

2. Silicon dominates thermal shrinking

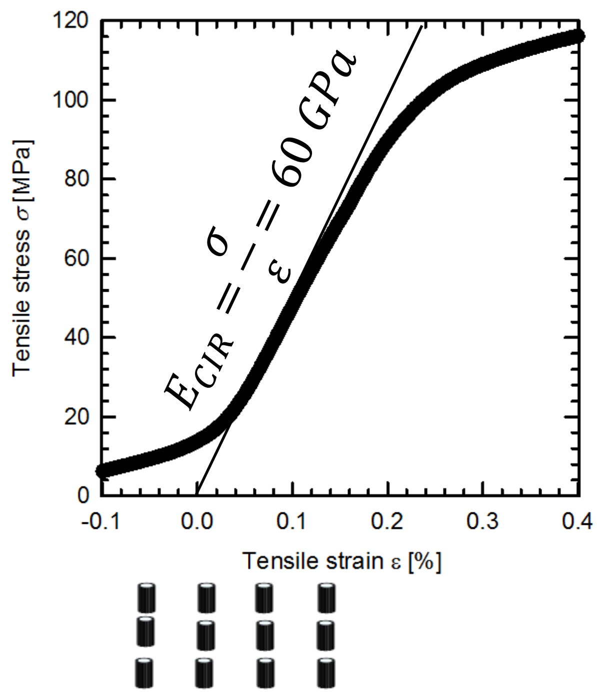
$\varepsilon = 0.22\%$

- Solder solidifies at about 180 °C → CIR connects to initially bowed solar cell
- Thermal shrinking during cool down

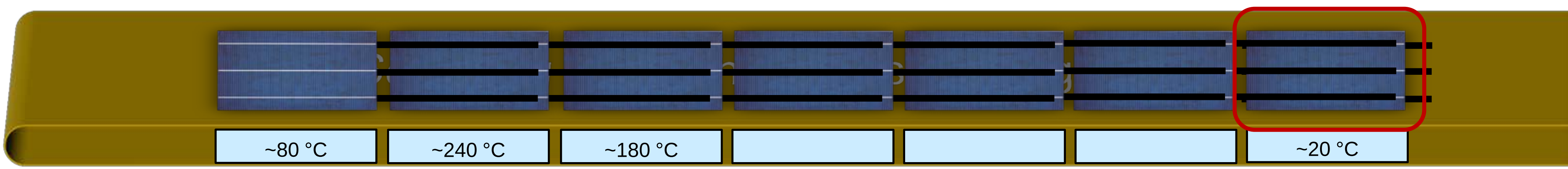


Tensile test of CIR

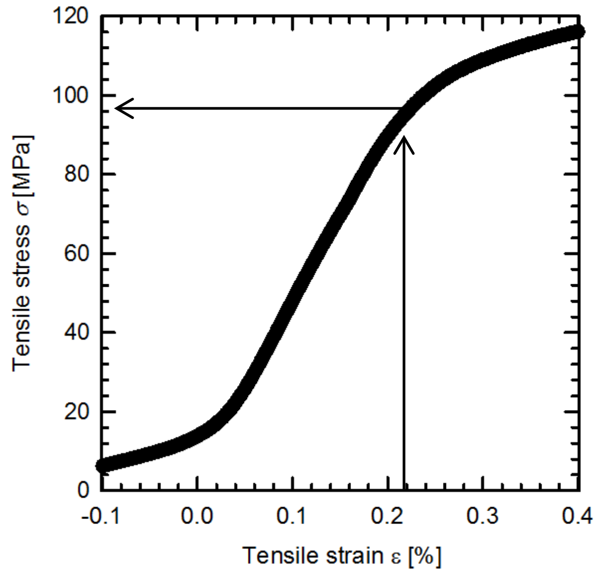
ε = 0.22%



- Solder solidifies at about 180 °C → CIR connects to initially bowed solar cell
- Thermal shrinking during cool down



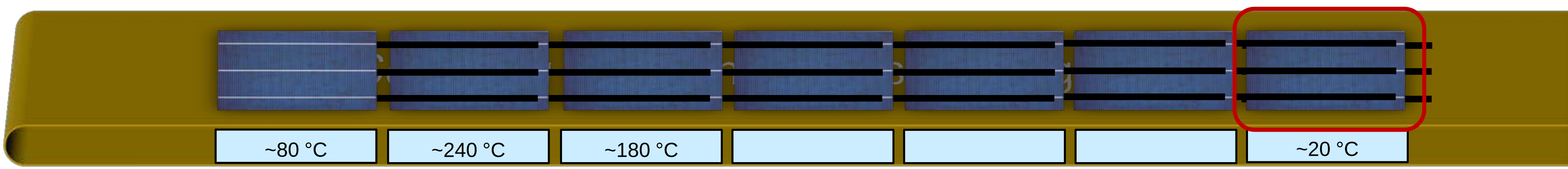
Stress in CIR



ε = 0.22%

σ = 96 MPa

- Solder solidifies at about 180 °C → CIR connects to initially bowed solar cell
- Thermal shrinking during cool down



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Influence of solder on stress

$$\varepsilon_{yield\_solder} = \frac{Yield\ stress}{Young's\ modulus}$$

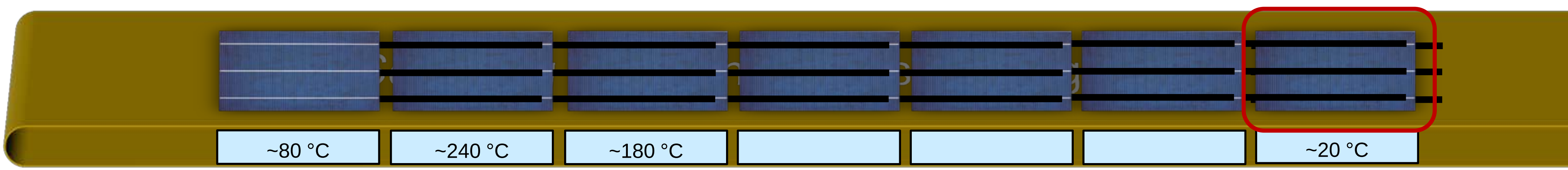
$$= \frac{43\ MPa}{18\ GPa} = 0.24\%$$

T. Siewert, S. Liu, D. R. Smith, J. C. Madeni; Database for solder properties with emphasis on new lead-free solders; NIST & Colorado School of Mines

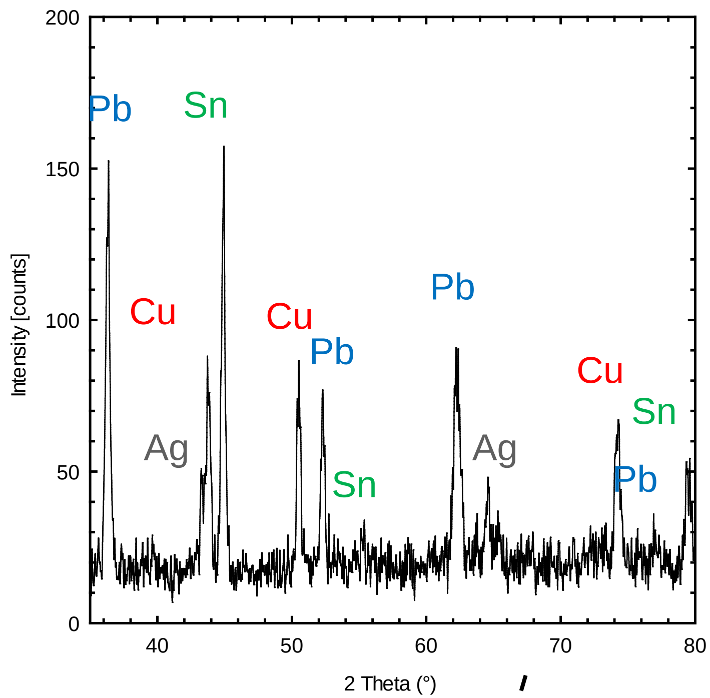
$\varepsilon = 0.22\%$

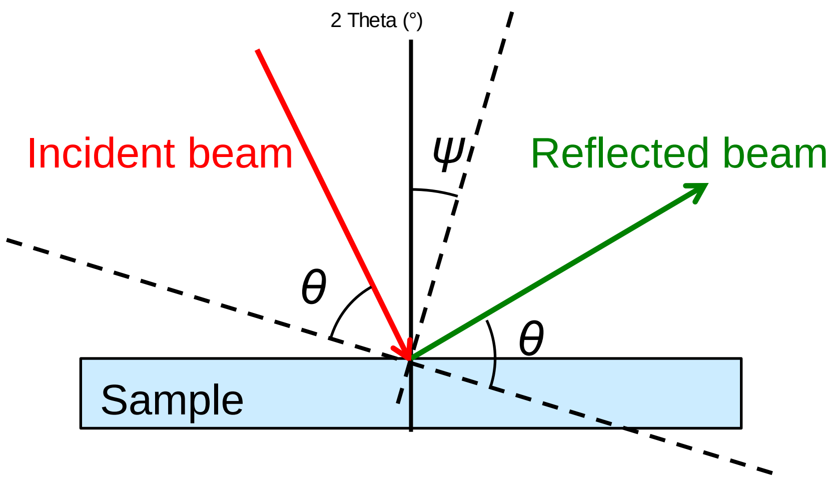
$\sigma = 96$ MPa

- Solder solidifies at about 180 °C → CIR connects to initially bowed solar cell
- Thermal shrinking during cool down
- Exceeding of solder yield strain? → No CIR relaxatio



Stress measurement by XRD

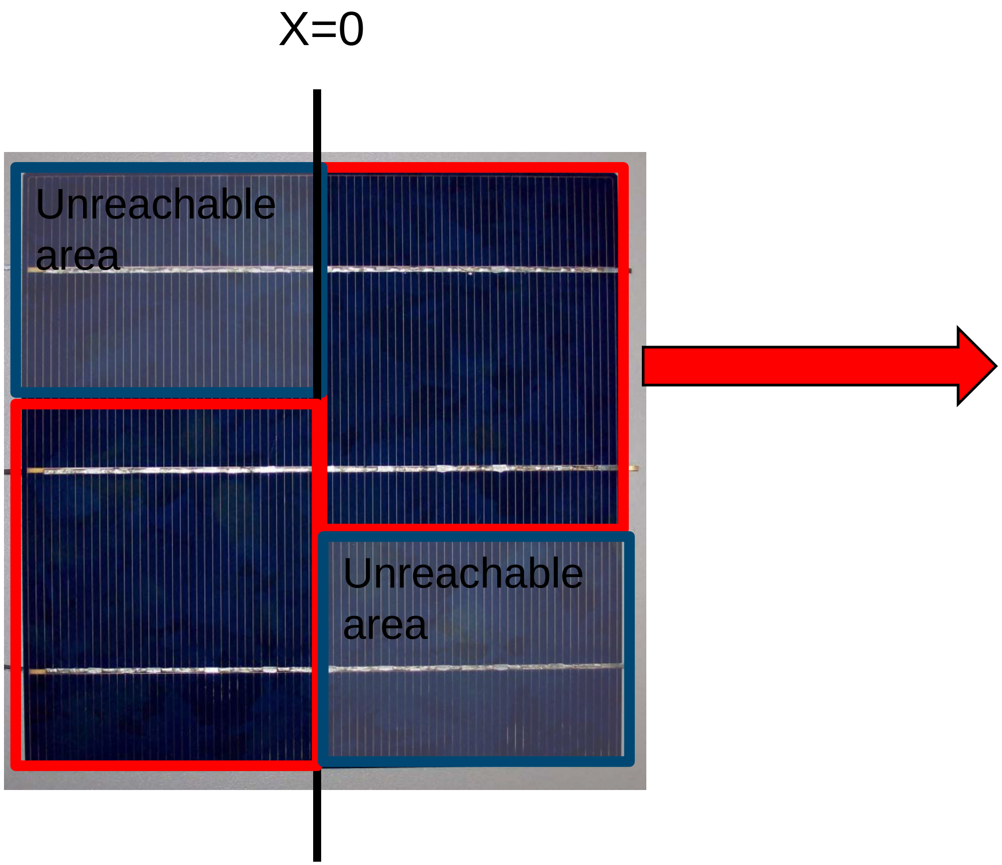


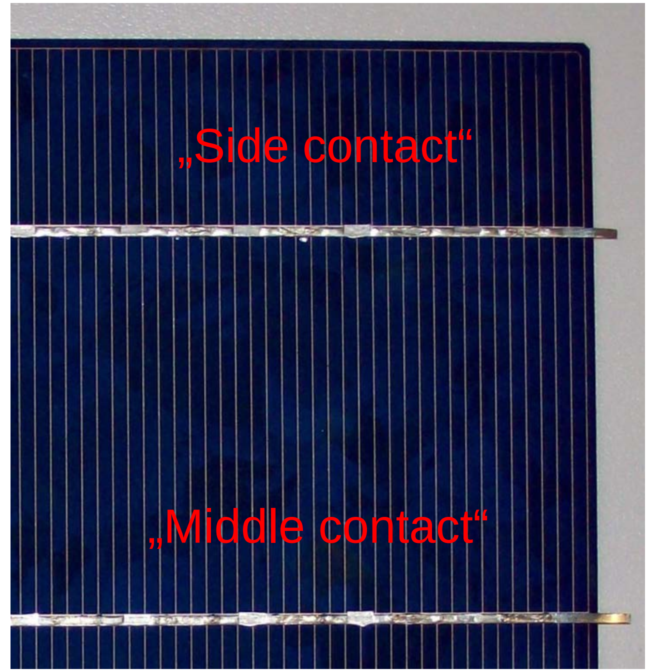


- Empyrean system from Panalytical with Cu-X-ray tube
- Measurement of Cu lattice plane distance changes
- Goniometer scan at 2Θ = 76°

M. Birkholz, Thin film analysis by X-Ray scattering, Wiley-VCH Verlag, Weinheim, 2006.

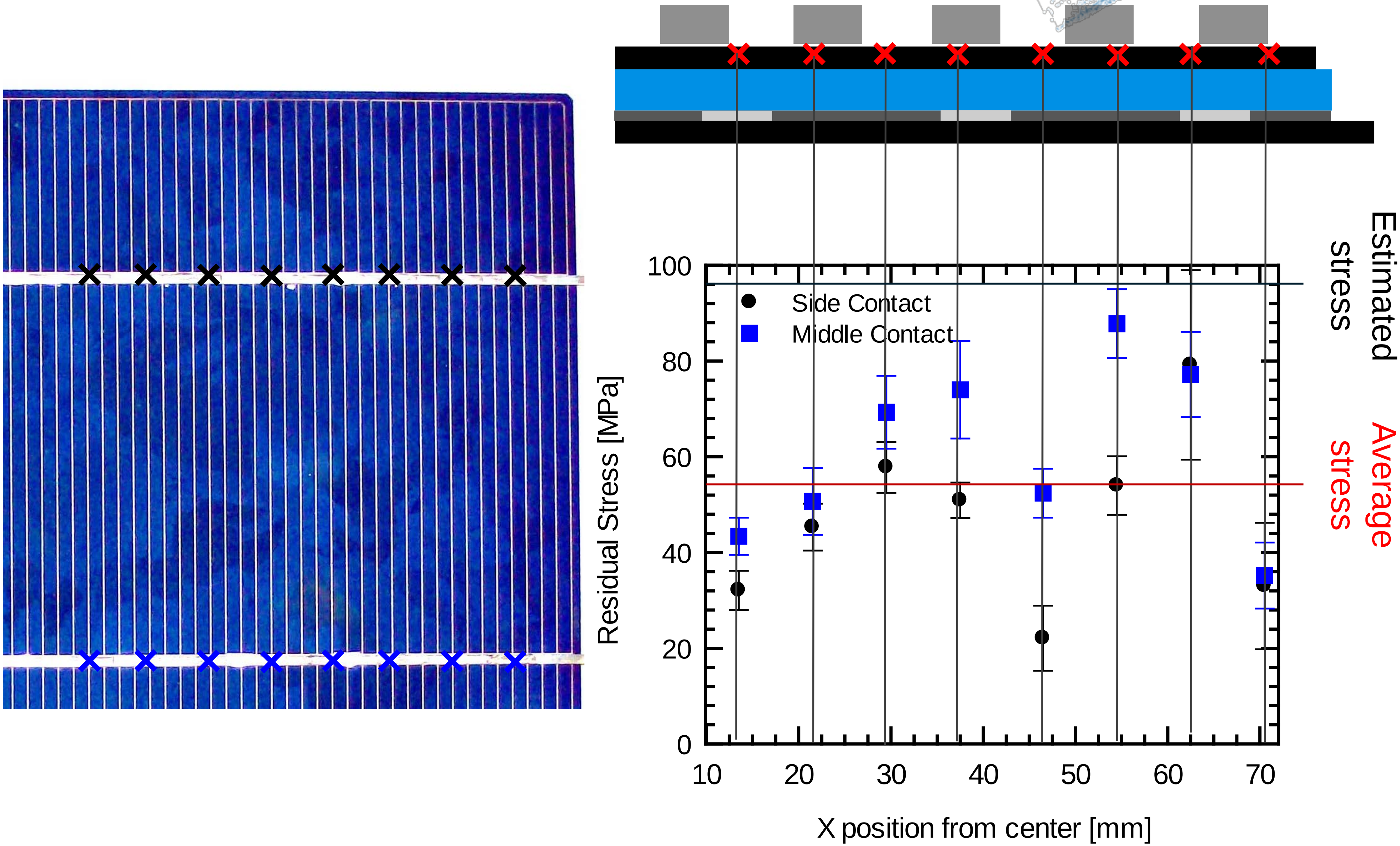
Stress measurement in CIR



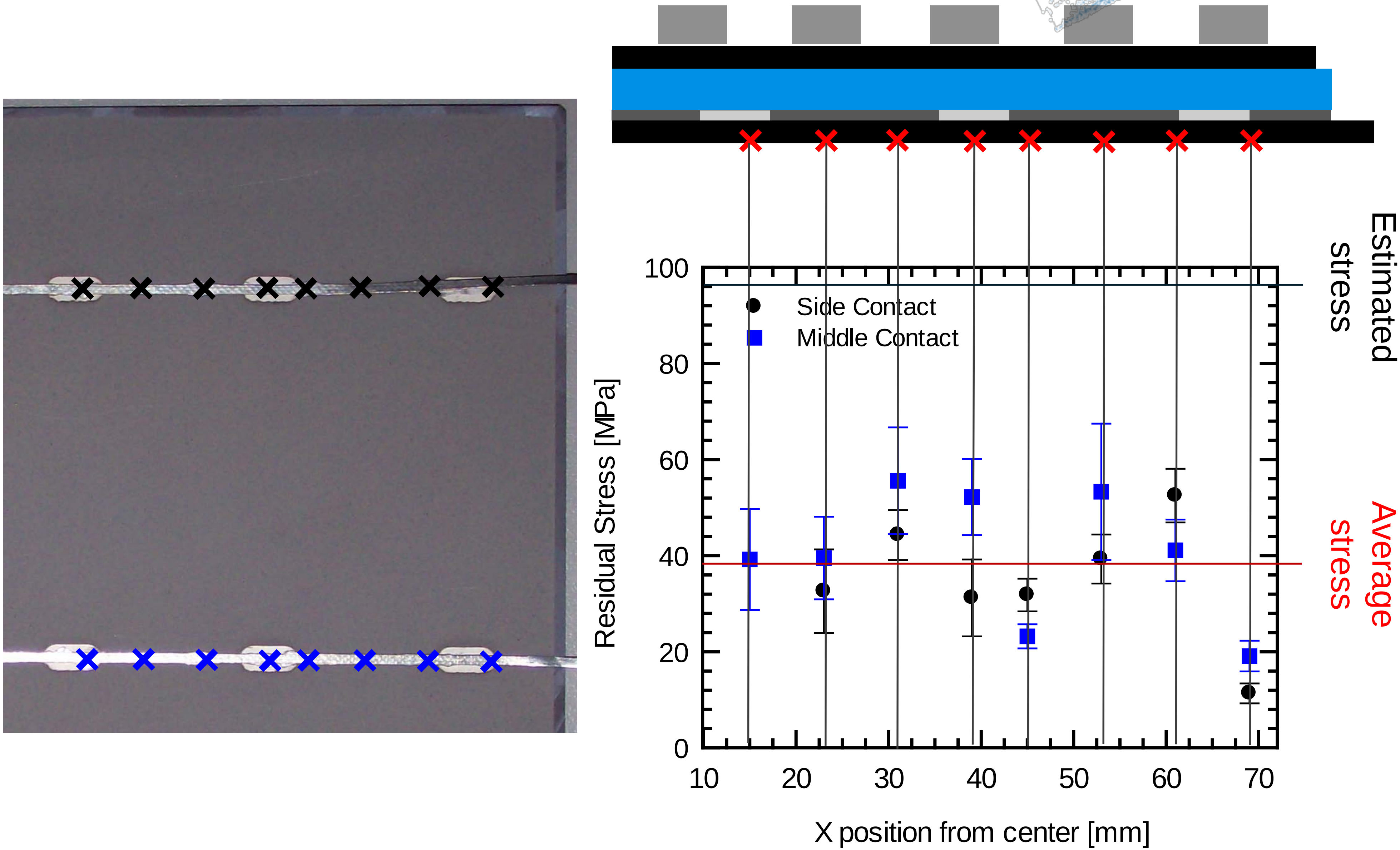


- Cell laid on a flat surface, without strain, 2.1 mm initial bow
- Spatially limited measurement due to sample holder geometry

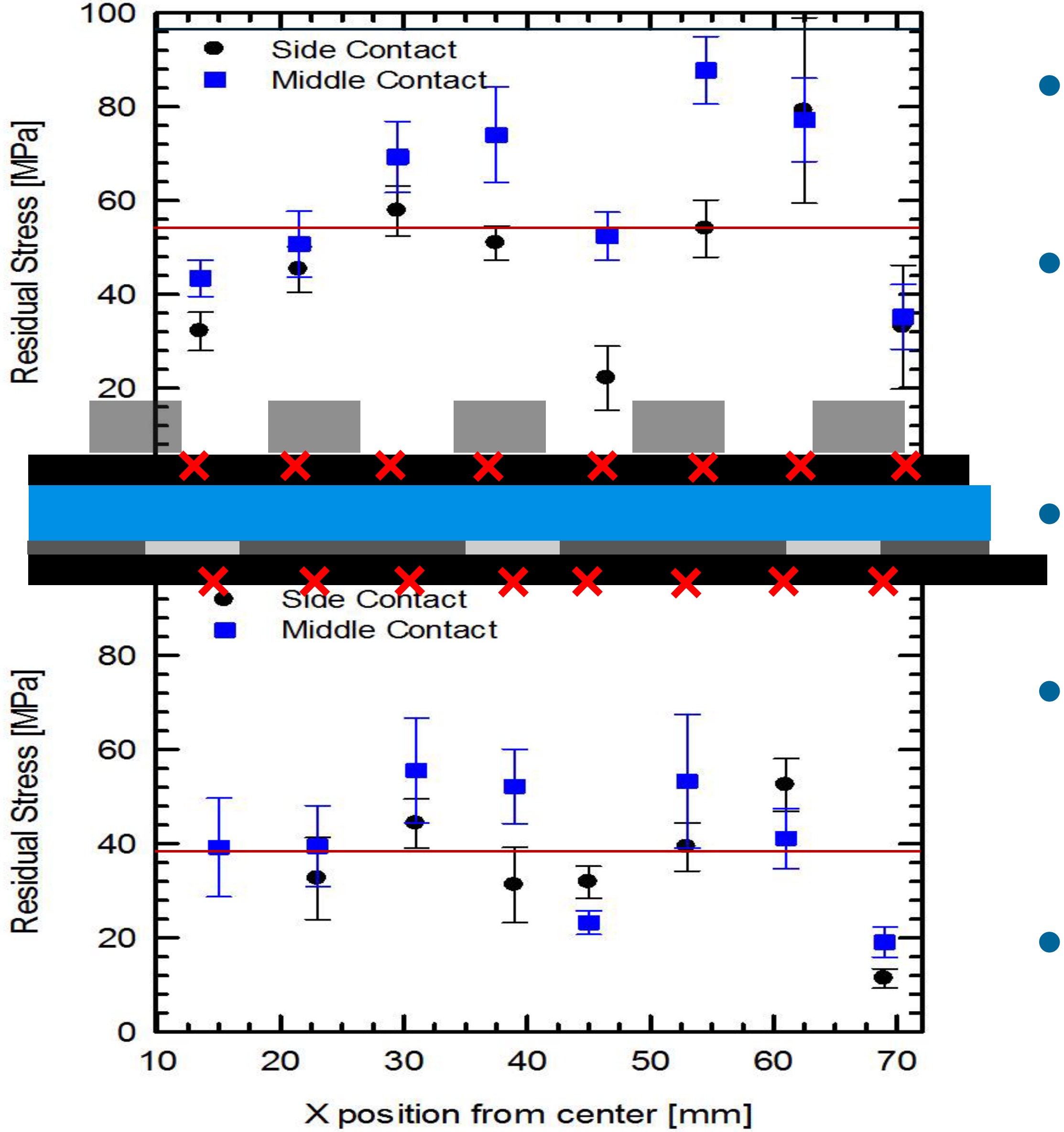
Front side stress



Rear side stress

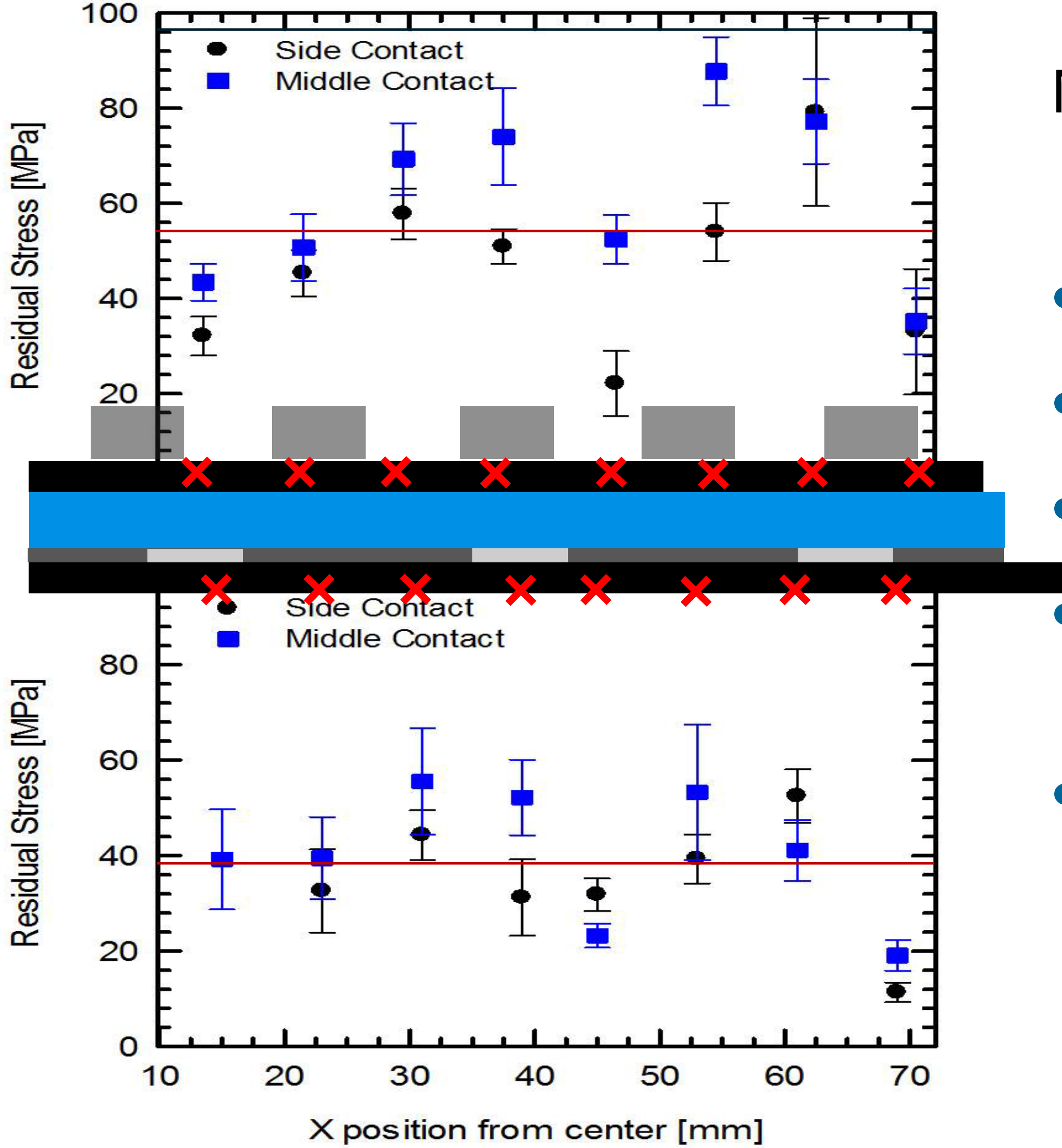


Stress comparison



- Maximum stresses fit to estimations
- Most measurments at about half of estimated stress (48 MPa)
- Similar stress pattern on all CIR on one cell
- Average rear side stress 16 MPa lower than front side stress
- Stress decrease at edge

Origin of stress pattern

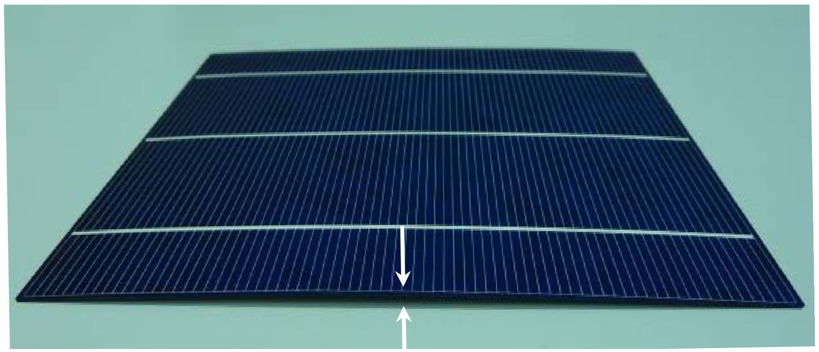


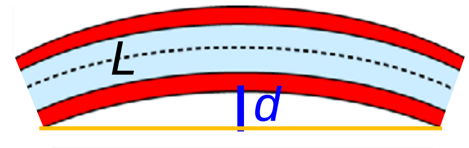
No correlation with:

- Solder head pattern
- Metallization pattern
- Thicknesses of materials
- Homogeneous material properties of CIR
- Initial bow → temperature profile

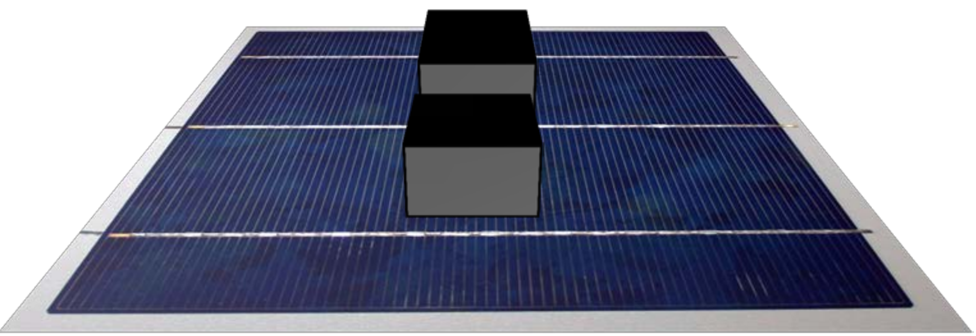
Flattening of solar cells similar to lamination process

Assumptions:





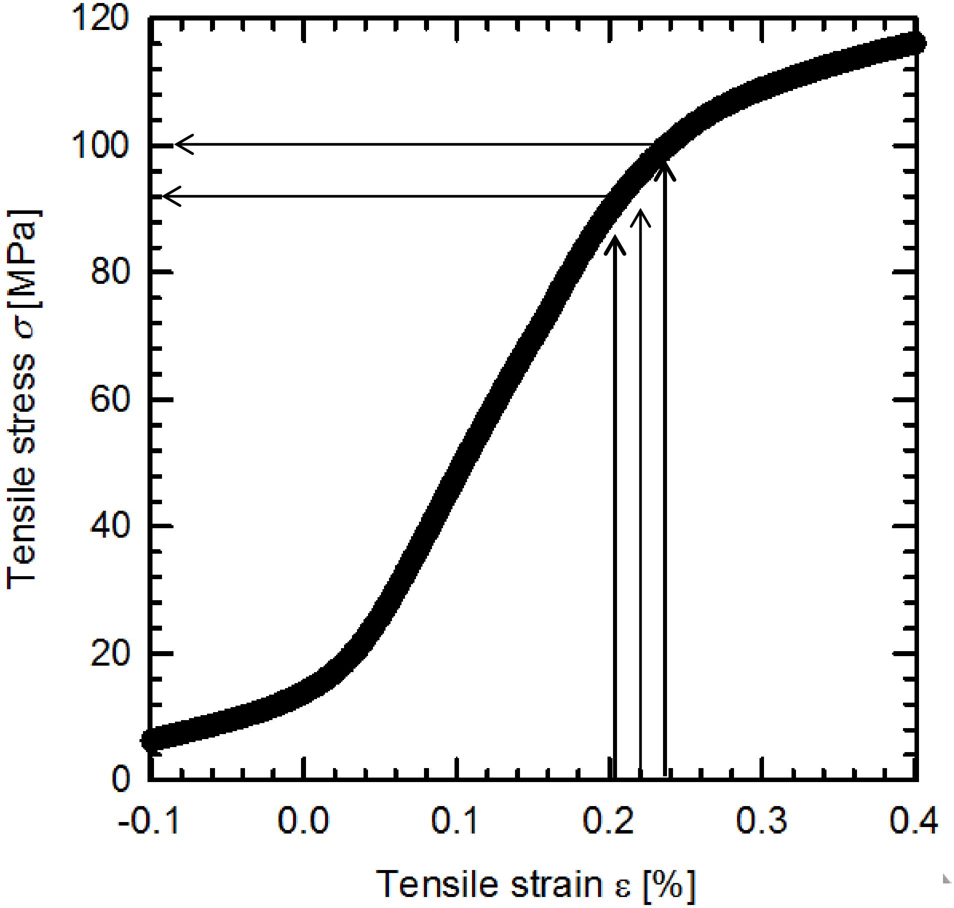
$$L = 156\,mm;\ d = 2.1\,mm$$
$$d_{cell} = 0.2\,mm;\ d_{CIR} = 0.15\,mm$$



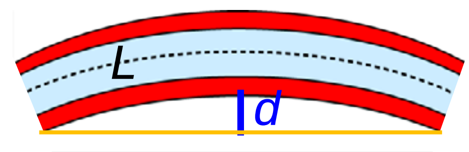
$$\Delta\varepsilon = -0.017\ \%$$

$$\Delta\varepsilon = +0.017\ \%$$

Variation of stress in CIR



Assumptions:

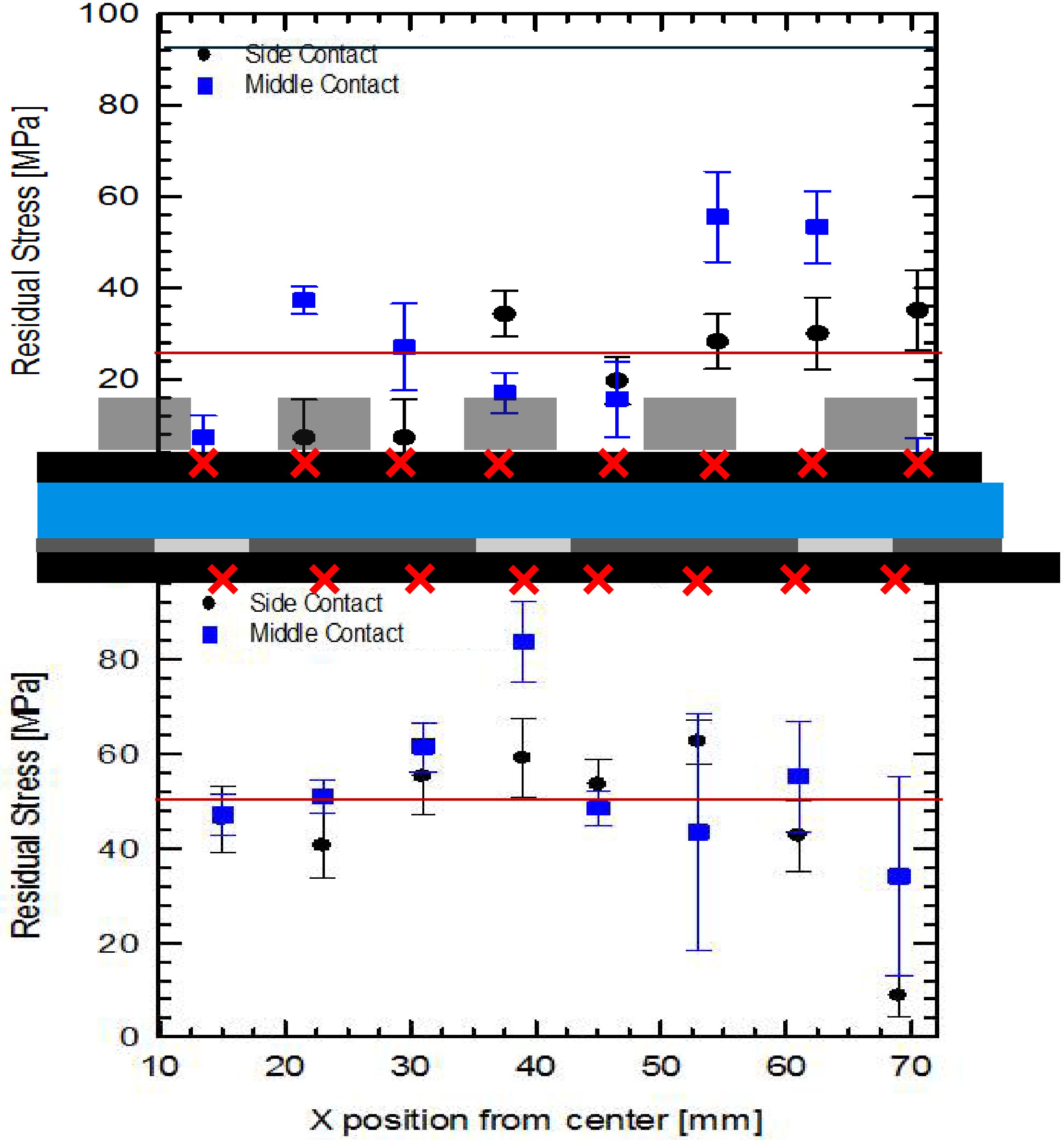


$$L = 156\,mm;\; d = 2.1\,mm$$
$$d_{cell} = 0.2\,mm;\; d_{CIR} = 0.15\,mm$$

$$\Delta\varepsilon = -0.017\,\%$$

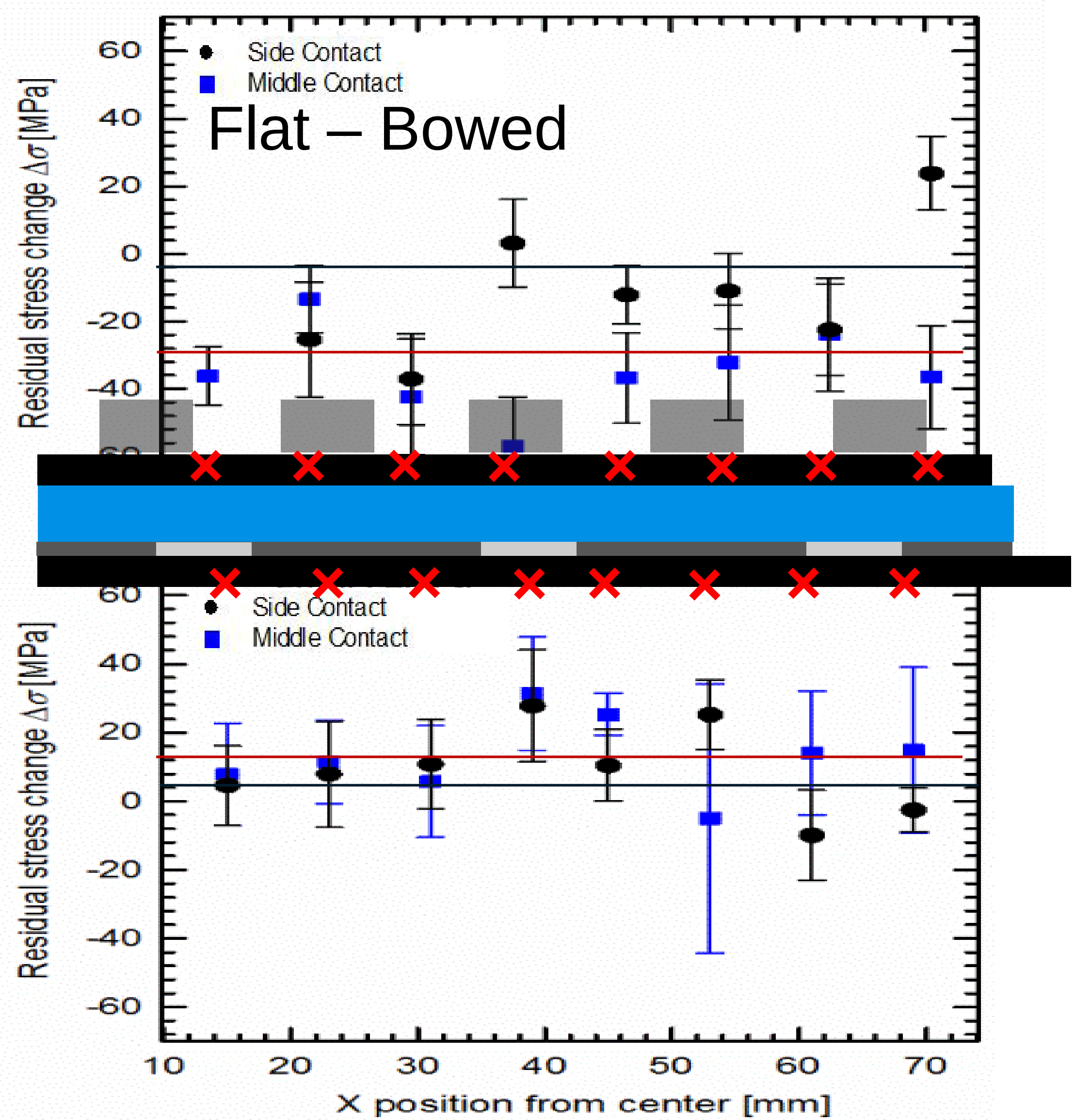
$$\Delta\varepsilon = +0.017\,\%$$

Stress in flattened solar cell



- Average front side stress is 25 MPa (67 MPa less than estimated)
- Average rear side stress is 50 MPa (50 MPa less than estimated)

Stress variation in CIR due to flattening of solar cell



- Average front side stress decrease (29 MPa) one order of magnitude more than estimated (4 MPa)
- Average rear side stress increase (12 MPa) in order of magnitude to estimation (4 MPa)

Conclusion

- Maximum measured CIR stresses close to estimated stress of 96 Mpa, but in average about half of it → further relaxation processes

- Initially bowed: 16 MPa more stress at front side

- Flattened: 25 MPa more stress at rear side

- Stress decrease at front side higher than increase at rear side due to flattening

- Similar stress pattern on every CIR of one solar cell

Gefördert durch:
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
aufgrund eines Beschlusses des Deutschen Bundestages

Leibniz Universität Hannover