Thermal Laser Separation for PERC and SHJ Solar Cells

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Fraunhofer Institute for Solar Energy Systems ISE

PV magazine webinar

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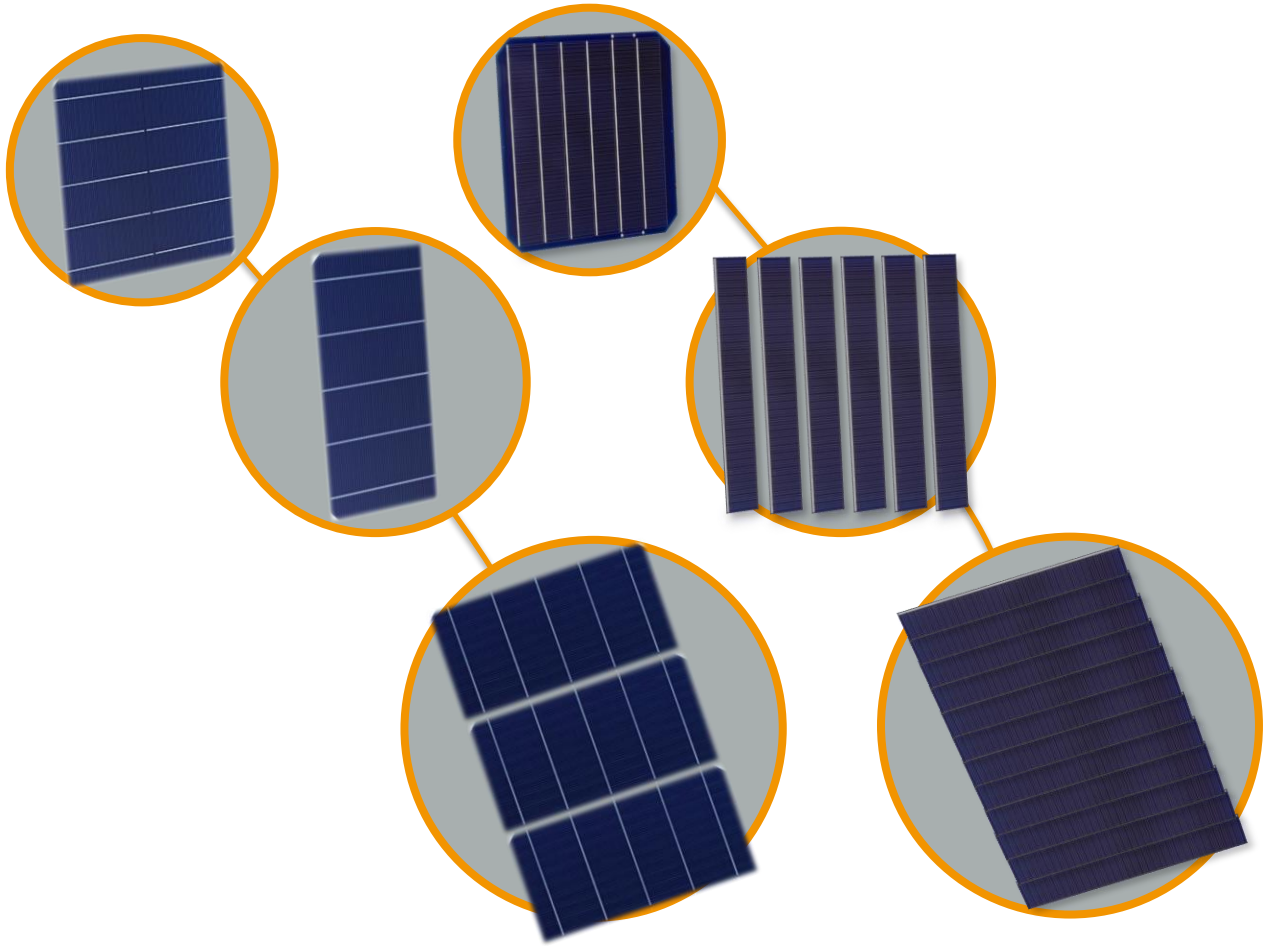
Approach
Separated Solar Cells

Full wafer-sized solar cells…
After contact formation

…separated
less current per cell

…interconnected into strings
ribbon-based or shingled



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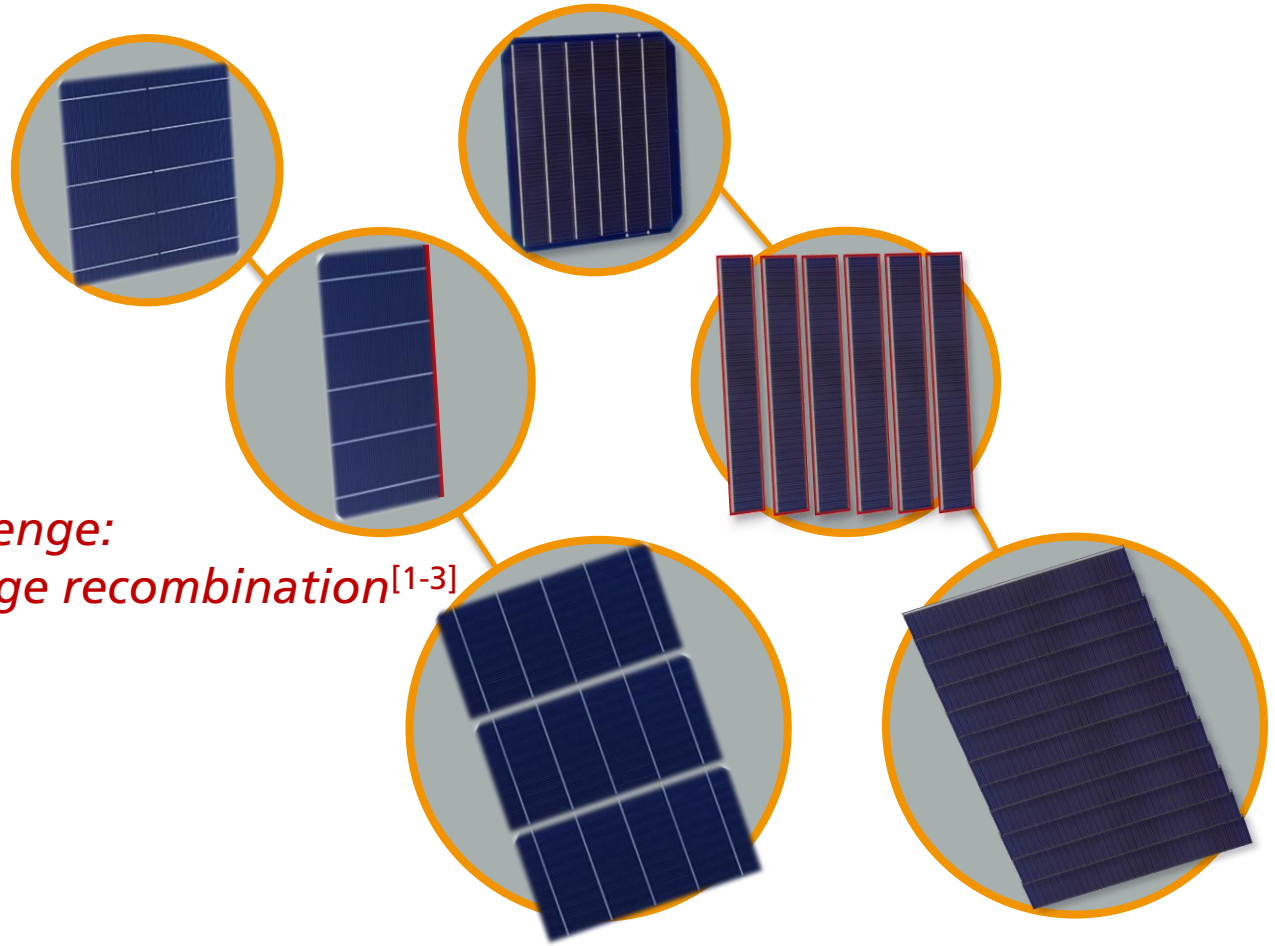

Challenge:
→ Edge recombination[1-3]

Higher impact for smaller cells with high perimeter-to-area ratios!

[1] K. R. Mcintosh, *PhD thesis, UNSW* (2001)
[2] J. Dicker. *Diss UniKonstanz* (2003)
[3] M. Hermle *et. al. 3rd WC-PVSC,* (2003)

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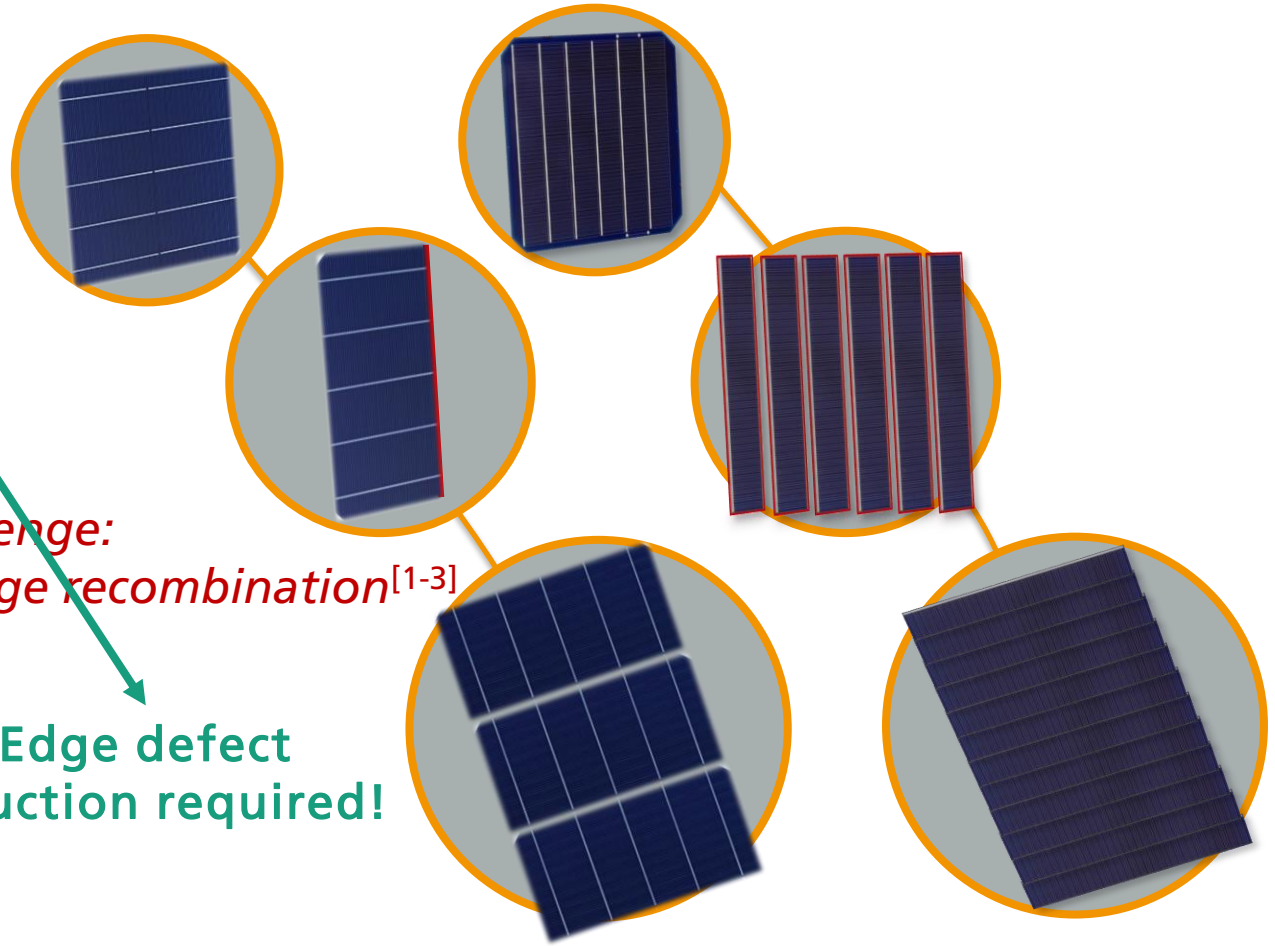
Edge defect reduction required!



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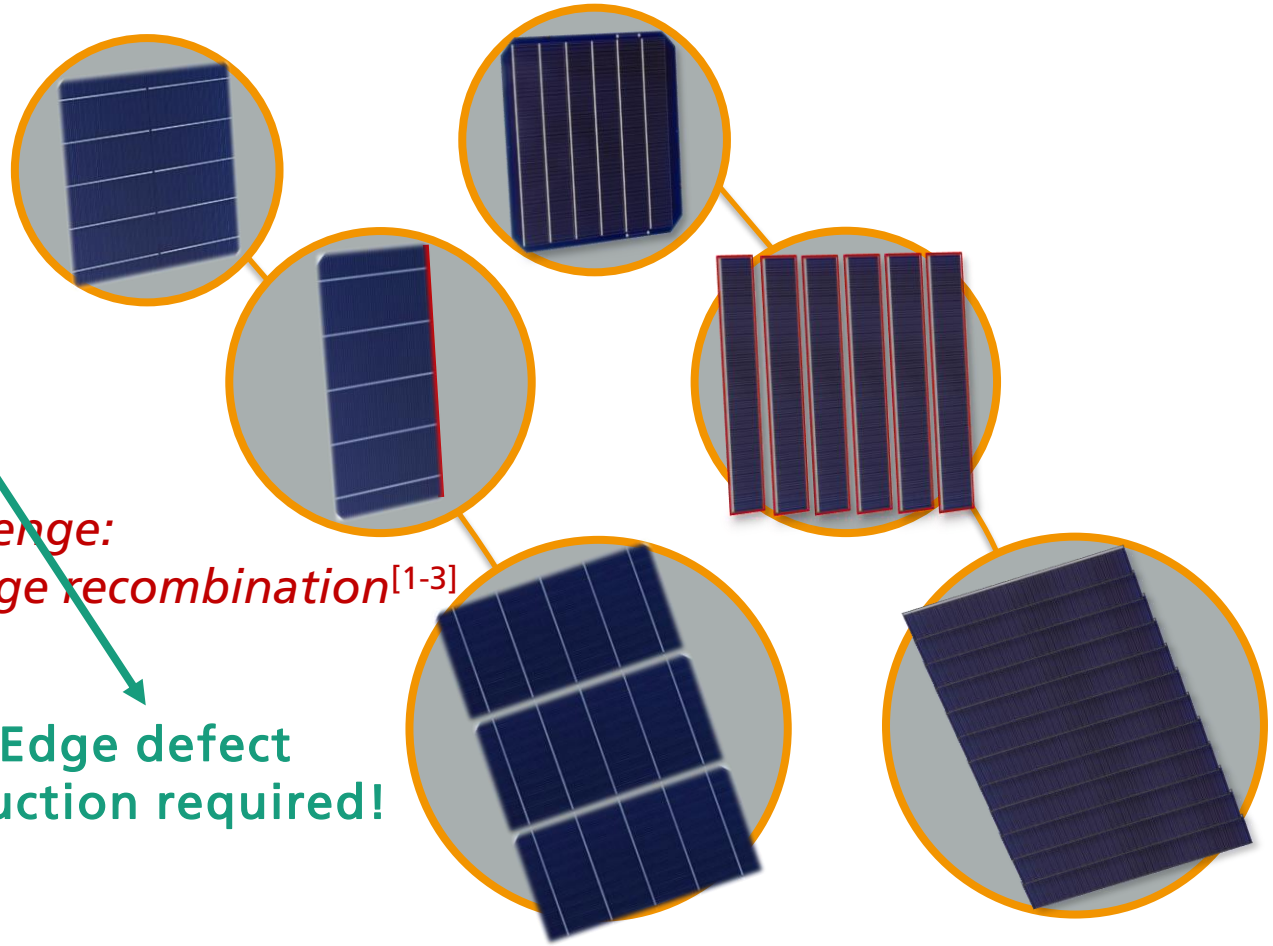


Challenge:
→ Edge recombination[1-3]

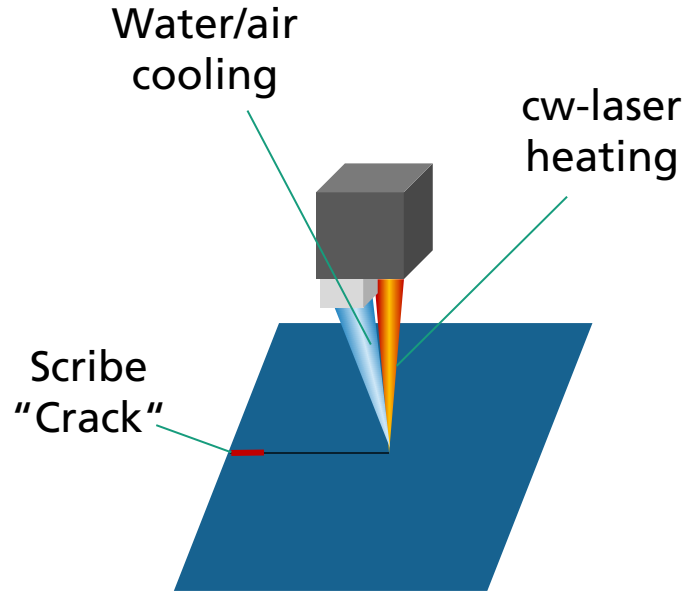
Edge defect reduction required!

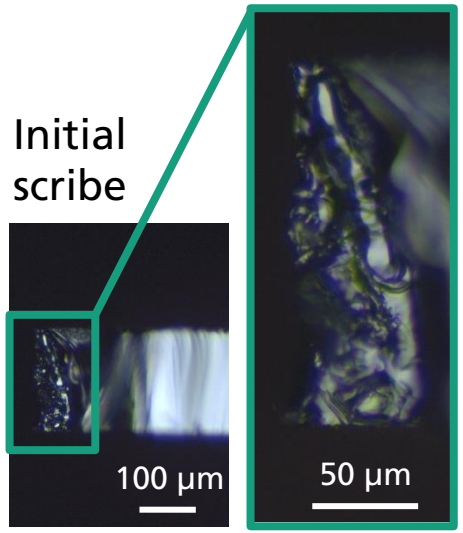
Defect poor separation for high electrical performance in addition to the mechanical stability

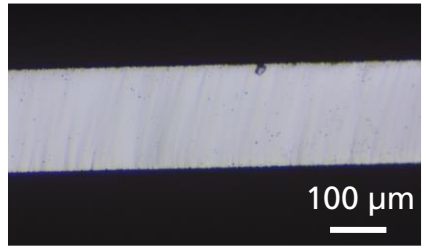
[1] K. R. Mcintosh, *PhD thesis, UNSW* (2001)
[2] J. Dicker. *Diss UniKonstanz* (2003)
[3] M. Hermle *et. al. 3rd WC-PVSC,* (2003)

Separation Process
Thermal Laser Separation

- Thermal laser separation (TLS)[1,2]
  1. **Scribe** process: initiates short crack (ablation)
  2. **Cleave** process: continuous wave (cw) laser-based heating and water/air cooling (no ablation)



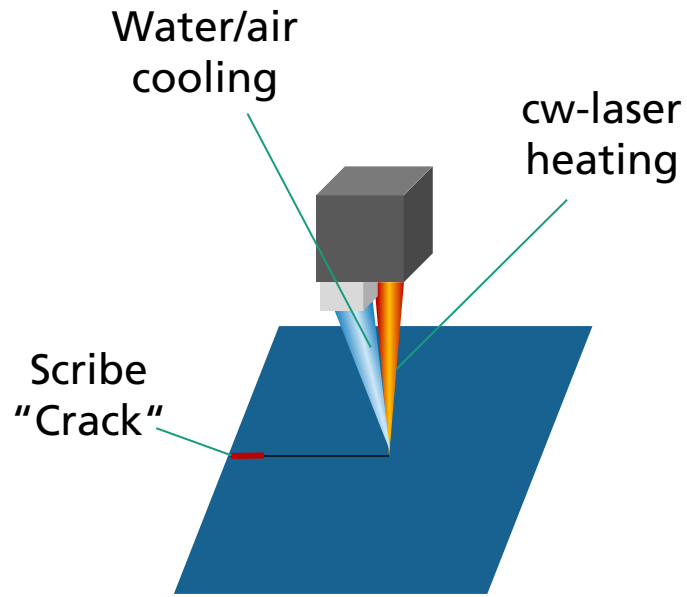


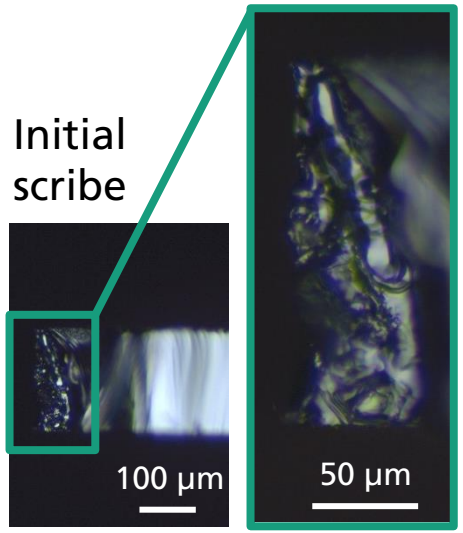


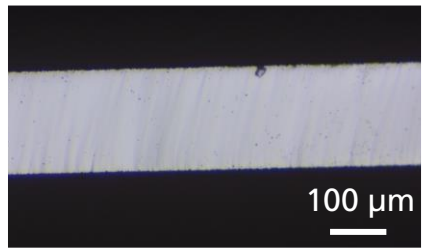
[1] H.U. Zuehlke, *CS Compound Semiconductor* (2016)
[2] https://3d-micromac.de/laser-mikrobearbeitung/produkte/microdice/ (online 2021)

Separation Process
Thermal Laser Separation

- Thermal laser separation (TLS)[1,2]
  1. **Scribe** process: initiates short crack (ablation)
  2. **Cleave** process: continuous wave (cw) laser-based heating and water/air cooling (no ablation)
- Cleave process
  → Temperatures below silicon melting point
- Might have an impact on already existing passivation layers of solar cells e.g.
  - Aluminum oxide (AlO_X) and silicon nitride (SiN_X) in PERC[3]
  - Hydrogenated amorphous silicon in SHJ[4]







[1] H.U. Zuehlke, *CS Compound Semiconductor* (2016)
[2] https://3d-micromac.de/laser-mikrobearbeitung/produkte/microdice/ (online 2021)
[3] M. Kim *et al. Solar Energy* (2014)
[4] A. Dabirian *et al. SolMat* (2017)

PERC: passivated emitter and rear cell
SHJ: silicon heterojunction

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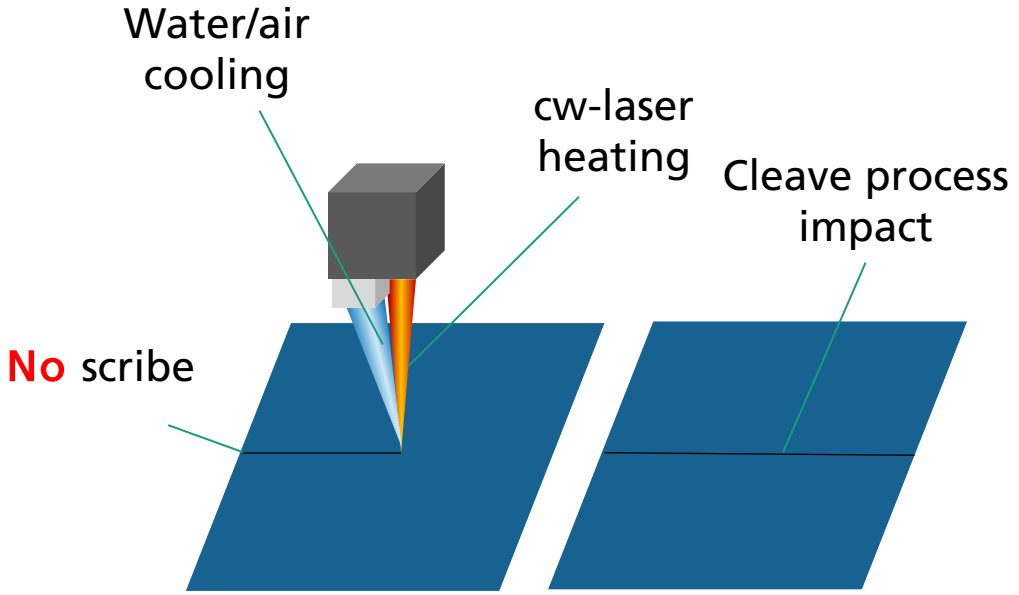
Separation Process
Cleave Process Optimization Method[1]

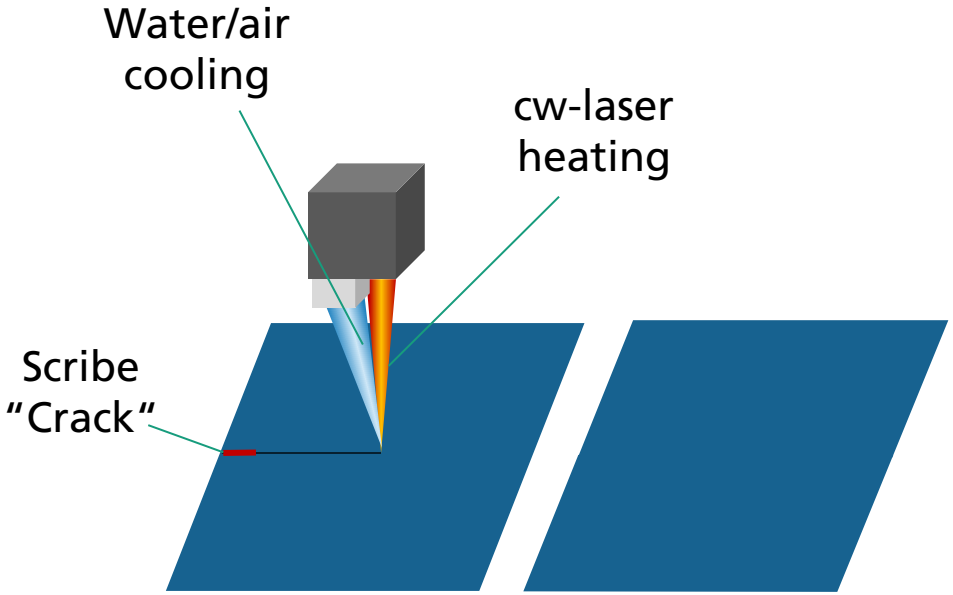
- Only cleave process (no scribe)
  - No separation → just cleave process impact



Scribe process	Cleave process	After processing wafer	Studied impact
OFF	ON	Full format	Cleave process

[1] P. Baliozian *et al.*, *IEEE JPV* (2021)

Separation Process
Cleave Process Optimization Method[1]



- Only cleave process (no scribe)
  - No separation → just cleave process impact
- Complete TLS (scribe + cleave)
  - Complete separation → cleave process and newly formed edge impact

Scribe process	Cleave process	After processing wafer	Studied impact
OFF	ON	Full format	Cleave process
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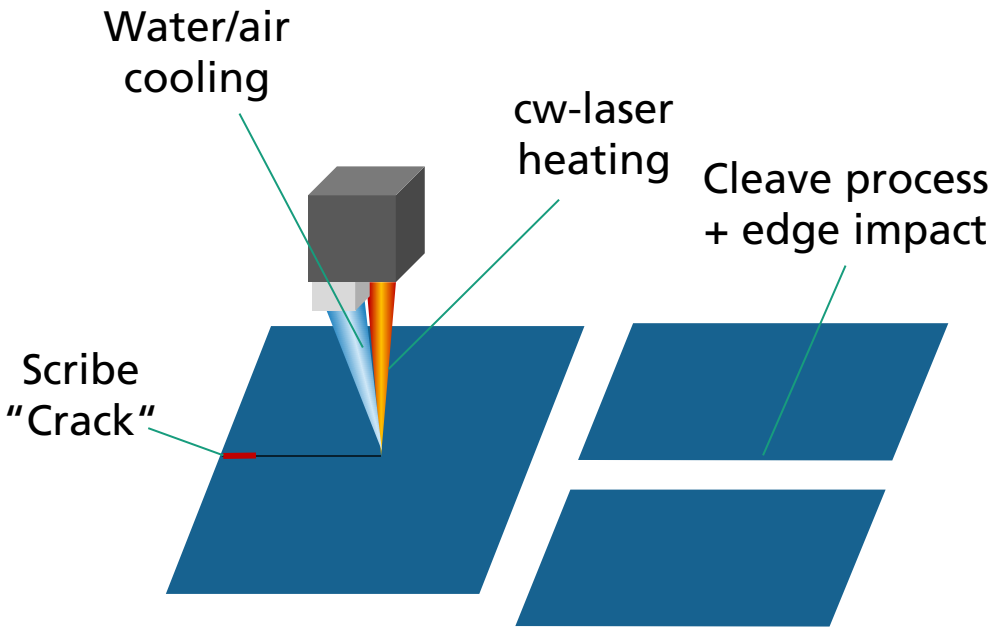


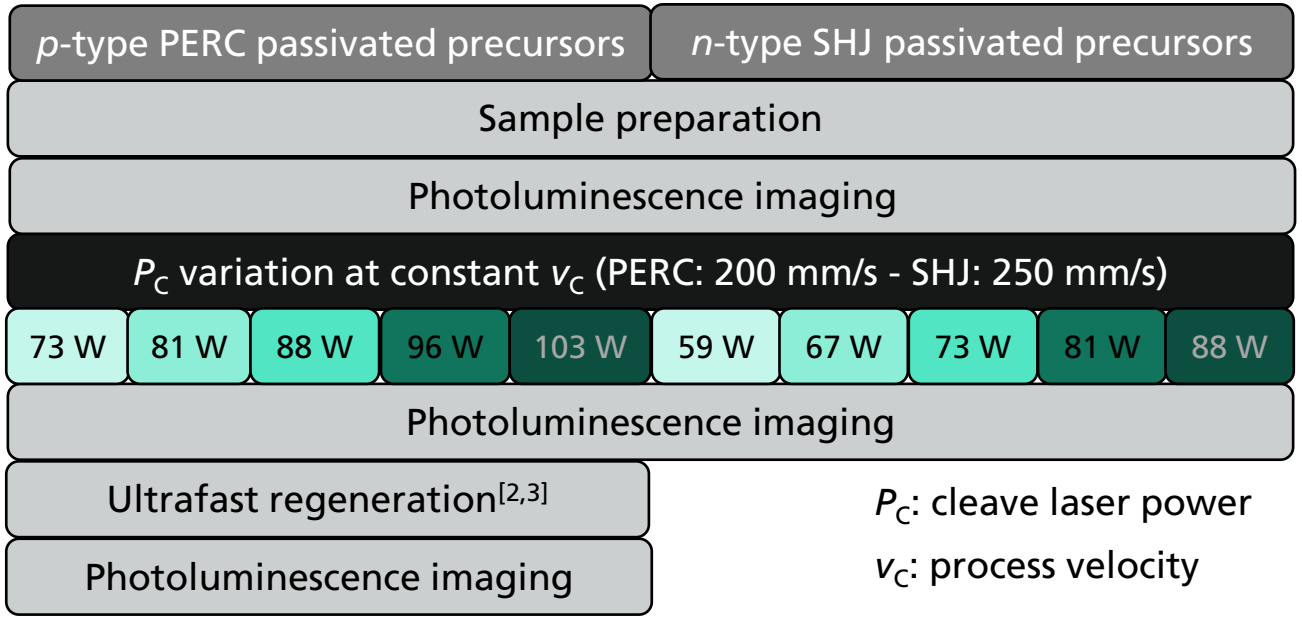
- Only cleave process (no scribe)
  - No separation → just cleave process impact
- Complete TLS (scribe + cleave)
  - Complete separation → cleave process and newly formed edge impact
- Photoluminescence imaging[2] before and after cleave parameter variation

Scribe process	Cleave process	After processing wafer	Studied impact
OFF	ON	Full format	Cleave process
ON	ON	Separated	Cleave process + edge

[1] P. Baliozian *et al.*, *IEEE JPV* (2021)
[2] H. Höffler *et al.*, *37th EUPVSEC* (2020)

Separation Process
Experimental Process Flow[1]

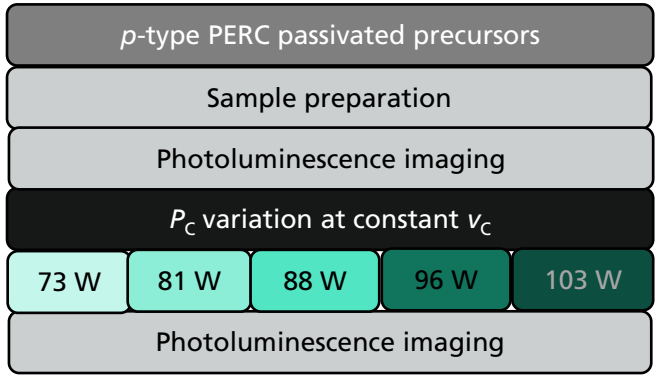
- Study the impact of cleave laser on **non-metallized** passivated precursors
  - *p*-type Cz-Si PERC
  - *n*-type Cz-Si SHJ



[1] P. Baliozian *et al.*, *IEEE JPV* (2021)
[2] A. A. Brand *et al.*, *33rd EUPVSEC* (2017)
[3] S. Roder *et al.*, *37th EUPVSEC* (2019)

PERC: passivated emitter and rear cell
SHJ: silicon heterojunction

Separation Process
Results[1]

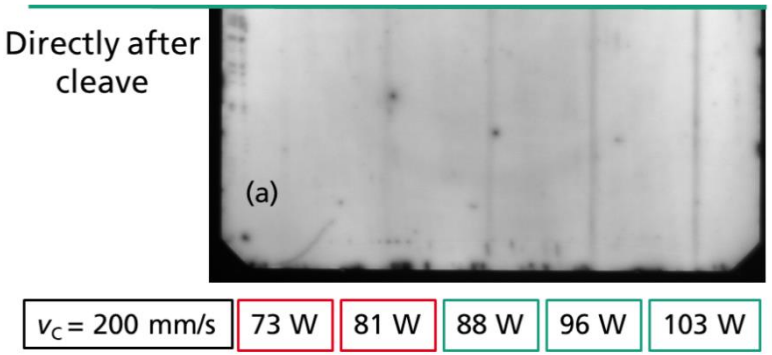


P_C: cleave laser power

v_C: process velocity

- **PERC:**
  - PL signal drop (ΔPL_S) measured directly after cleave process
  - ΔPL_S dependent on P_C

Lower PL signal **(darker regions)** means larger defects



PERC

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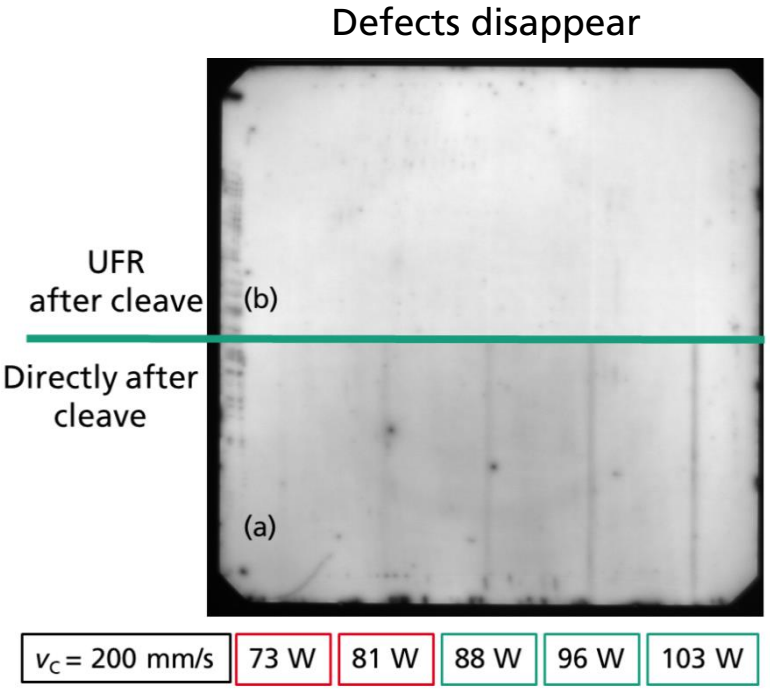
Separation Process
Results[1]

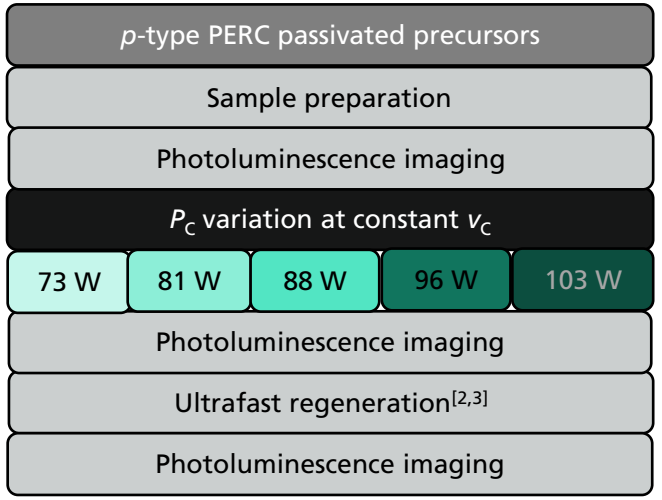
- **PERC:**
  - PL signal drop (ΔPL_S) measured directly after cleave process
  - ΔPL_S dependent on P_C
- PL regain after UFR process
  - Reversible impact
  - → No permanent damage

UFR: ultra fast regeneration

P_C: cleave laser power

v_C: process velocity





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- **PERC:**
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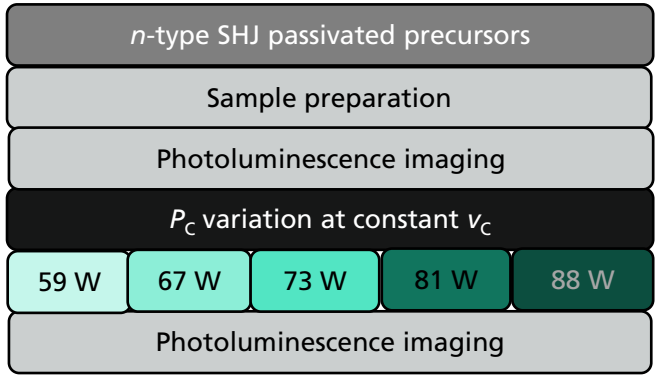
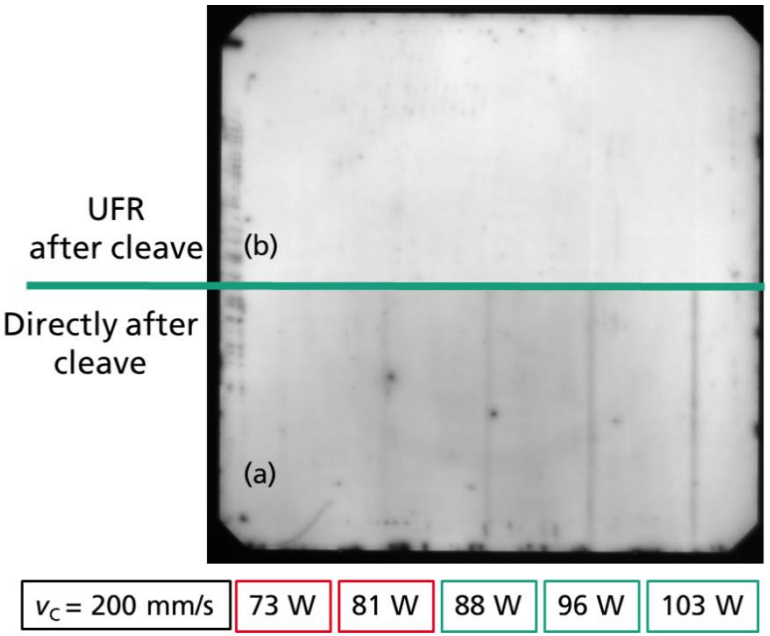
- **SHJ:**
  - PL signal drop (ΔPL_S) measured (dependent on P_C)

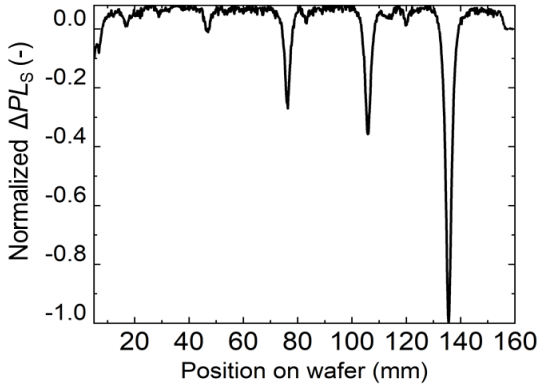
UFR: ultra fast regeneration

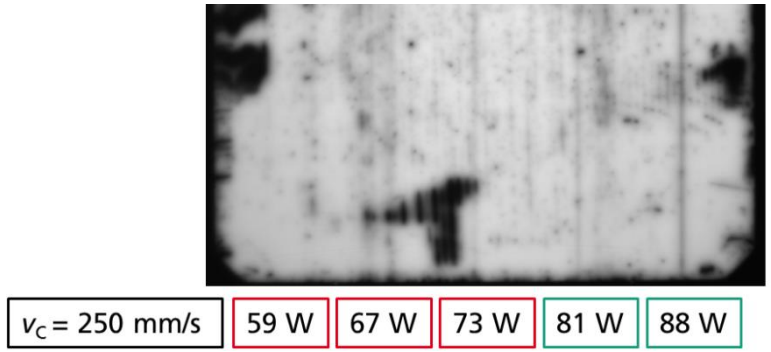
P_C: cleave laser power

v_C: process velocity









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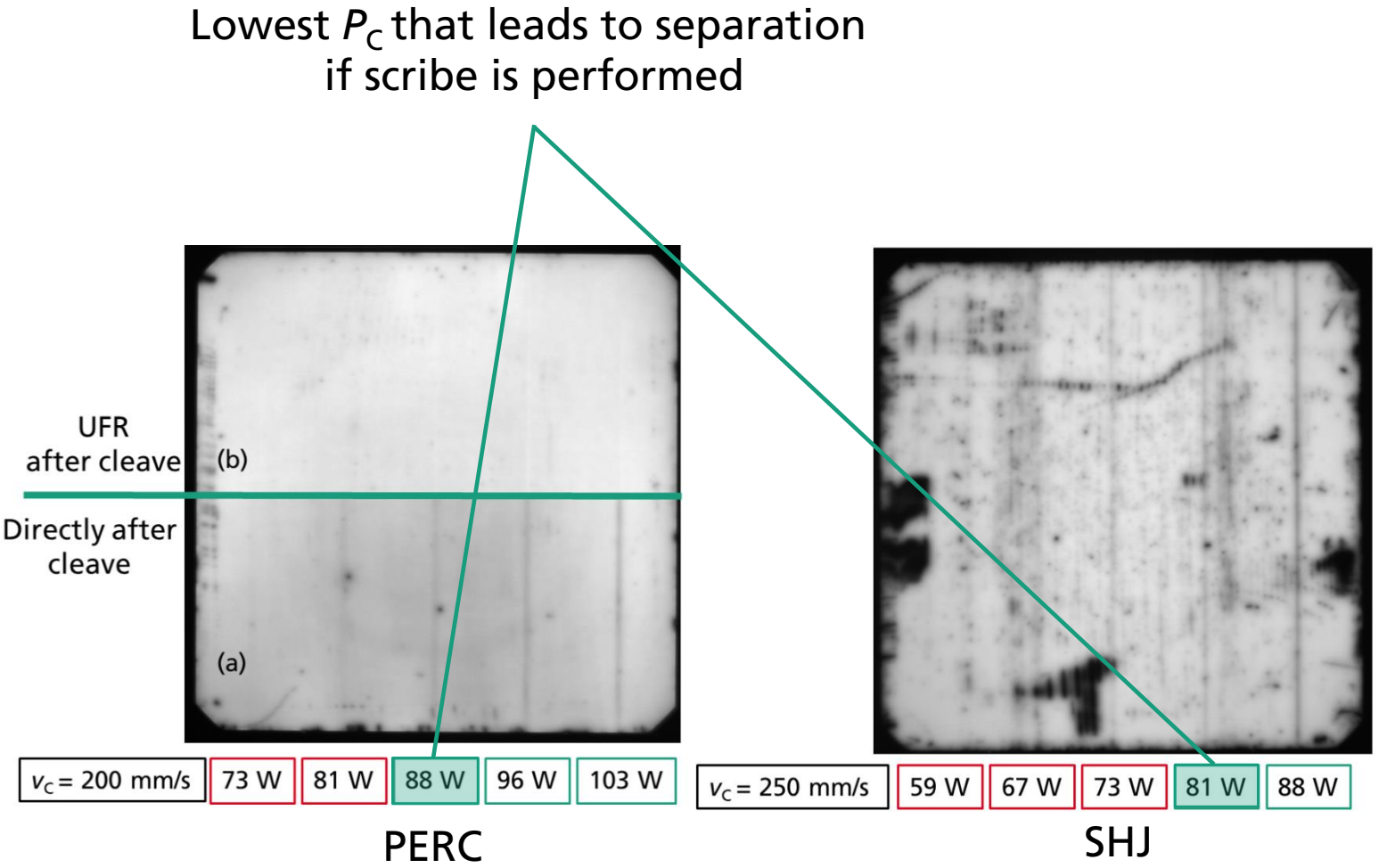
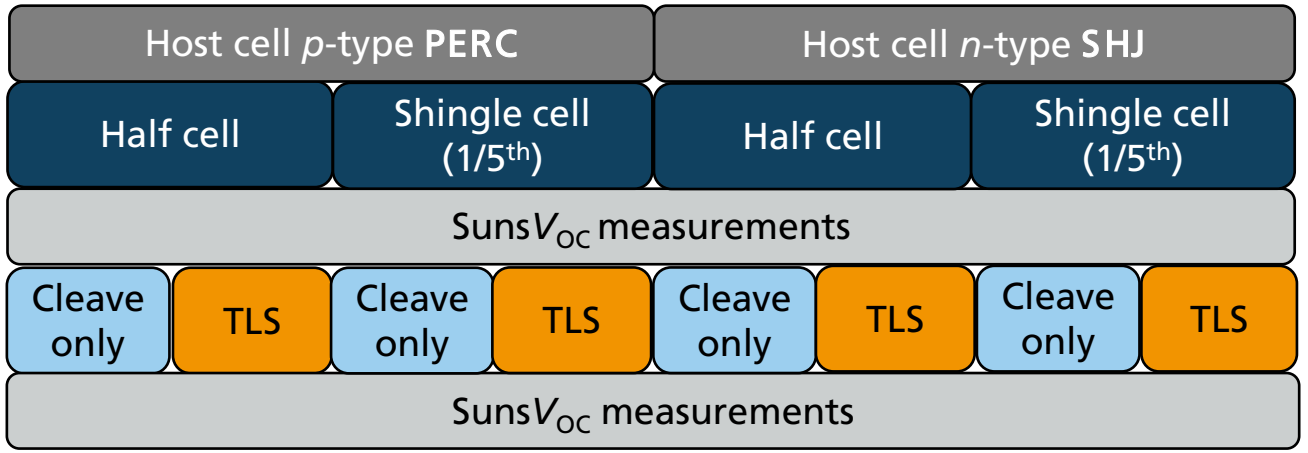


[1] P. Baliozian *et al.*, *IEEE JPV* (2021)

Separation Process
Metallized Host Cells – Experimental Process Flow[1]

- PERC and SHJ cells fabricated
  - Half cell format
  - Shingle cell format (shingle cell width = 31.35 mm)
- Characterization by SunsV_{OC} measurement[2-4]
  - Influence on the open-circuit voltage V_{OC} and pseudo-fill factor *pFF*



[1] P. Baliozian *et al., IEEE JPV* (2021)
[2] R. Sinton *et al., 9th Workshop Crystalline Silicon Solar Cell Materials and Processes* (1999)
[3] S. Bowden *et al., 29th IEEE PVSC* (2002)
[4] D. Bertrand *et al., IEEE JPV* (2017)

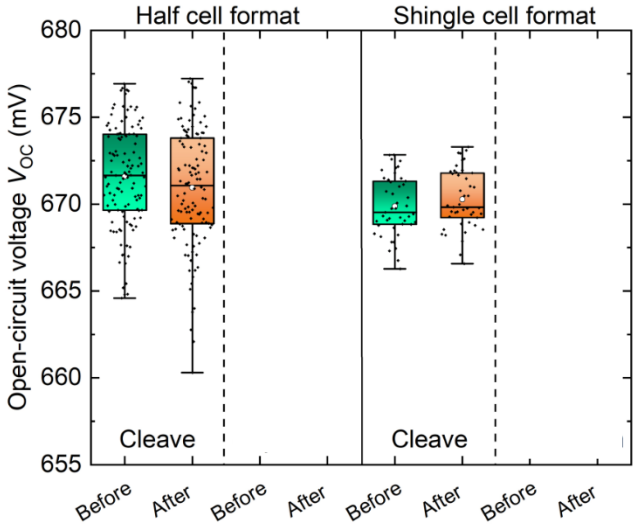
Separation Process

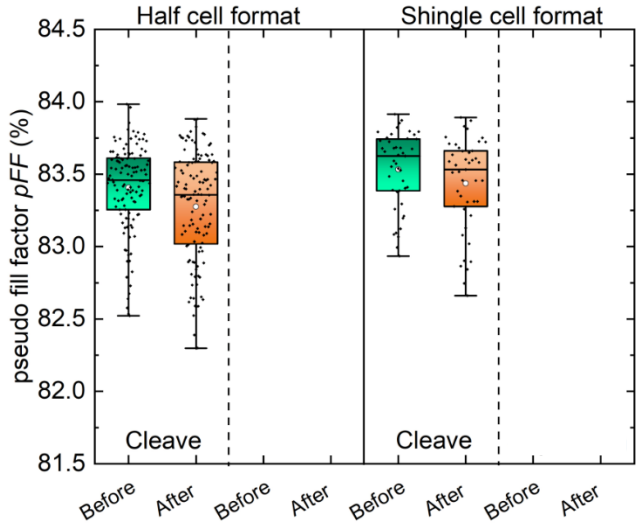
SunsV_{OC} Results[1]

Only cleave process:

- Minor impact on V_{OC} and *pFF*

PERC





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Separation Process

SunsV_{OC} Results[1]

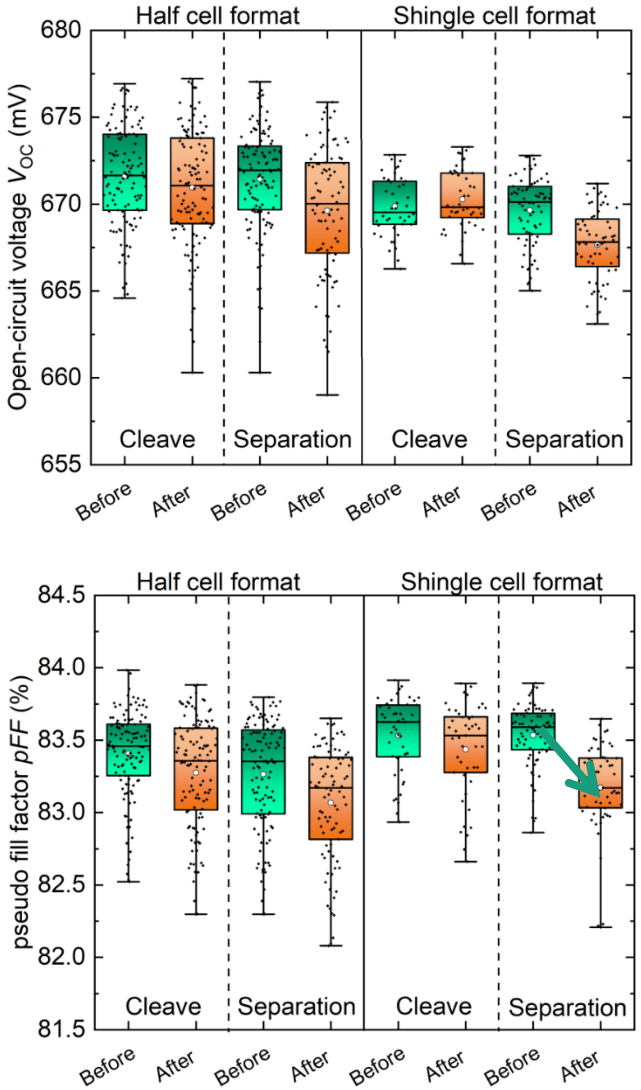
Only cleave process:

- Minor impact on V_{OC} and *pFF*

Complete separation:

- Few mV drop for half and shingle cells
- Highest *pFF* drop - 0.4%$_{abs}$ recorded after complete separation into shingle cells

PERC



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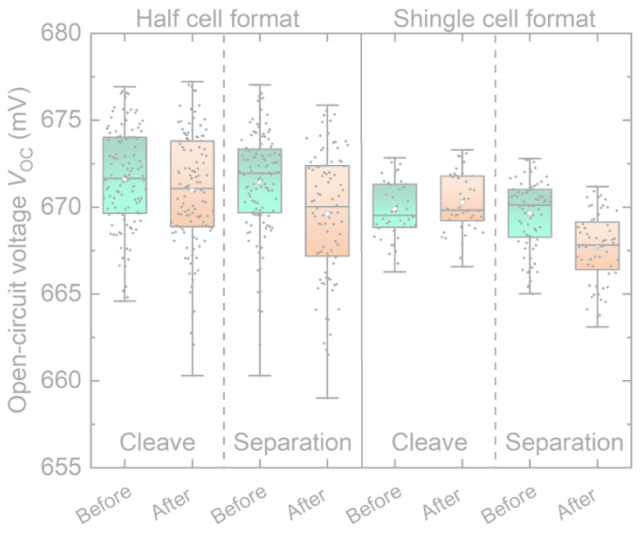
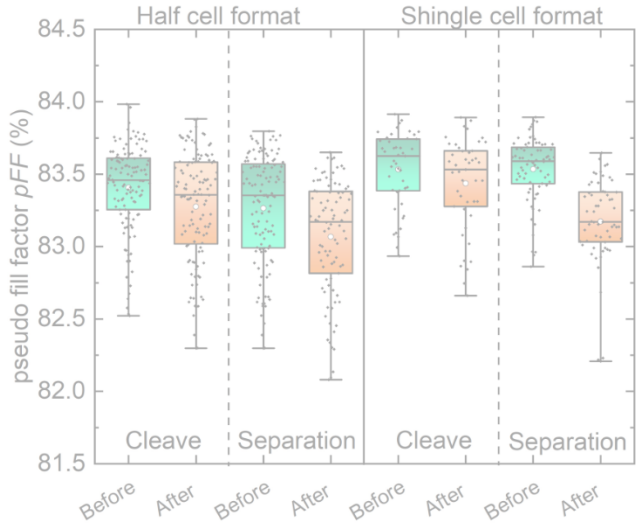
Separation Process
SunsV_{OC} Results[1]

Only cleave process:

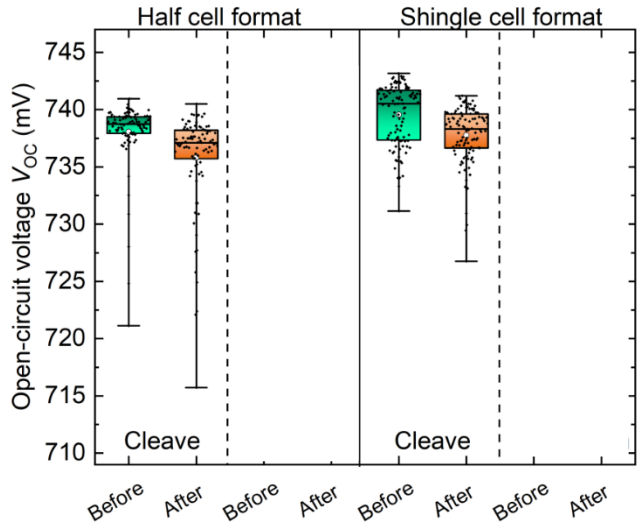
- Slight drop in V_{OC}
- Minor impact on *pFF* only in the case of shingle cells

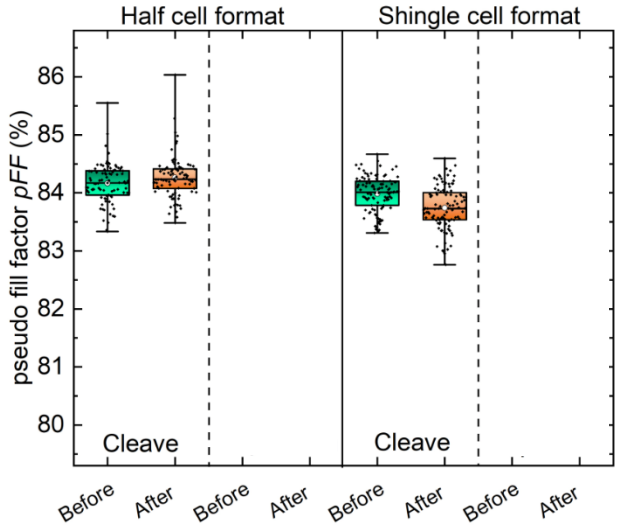
PERC





SHJ





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Separation Process
SunsV_{OC} Results[1]

Only cleave process:

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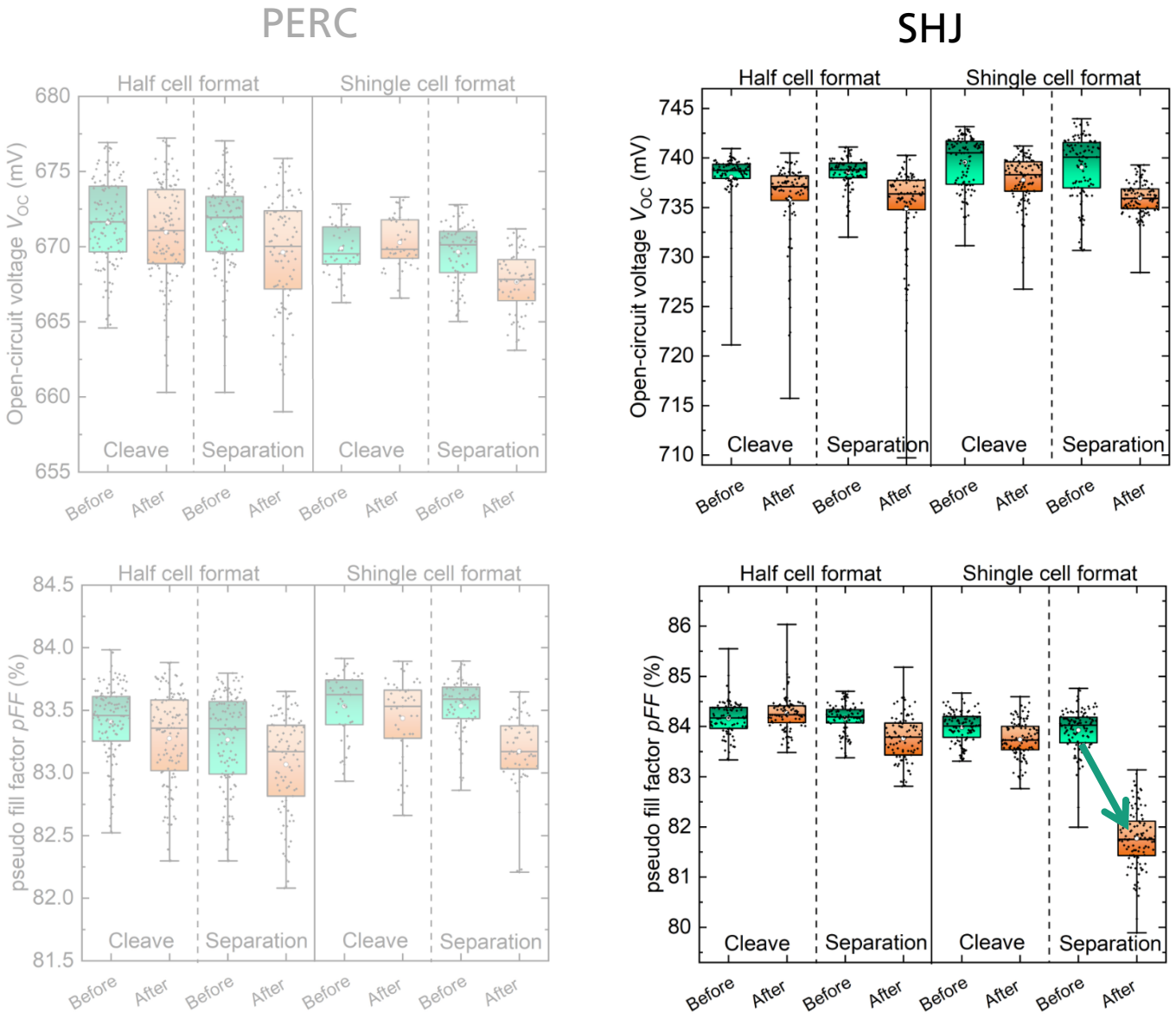
Complete separation leads:

- V_{OC} loss in the case of shingles around - 4 mV
- *pFF* drop
  - Half cells: - 0.4%$_{abs}$
  - Shingle cells: - 2.1%$_{abs}$



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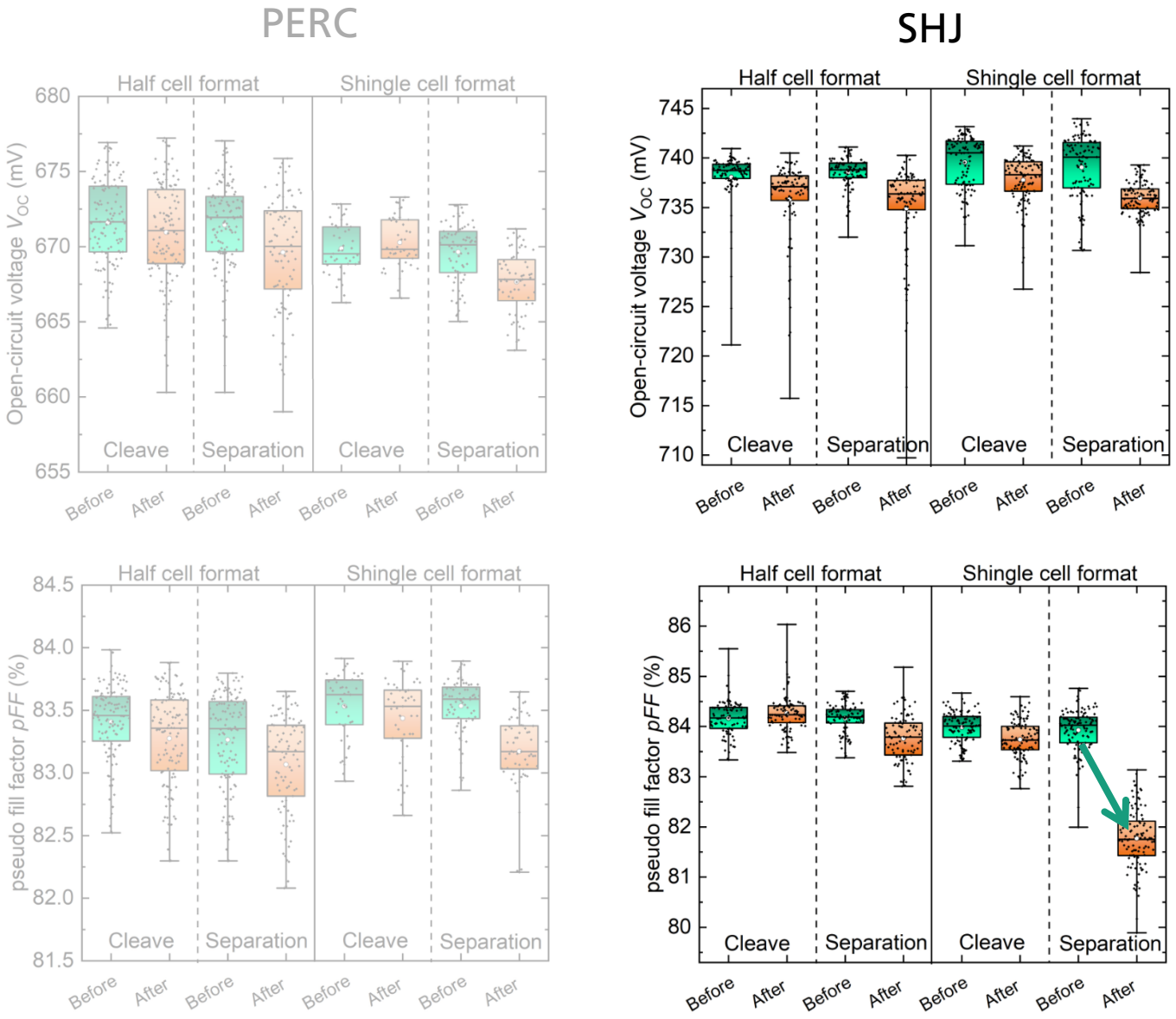
Deduction: main loss due to newly formed edge for both PERC and SHJ



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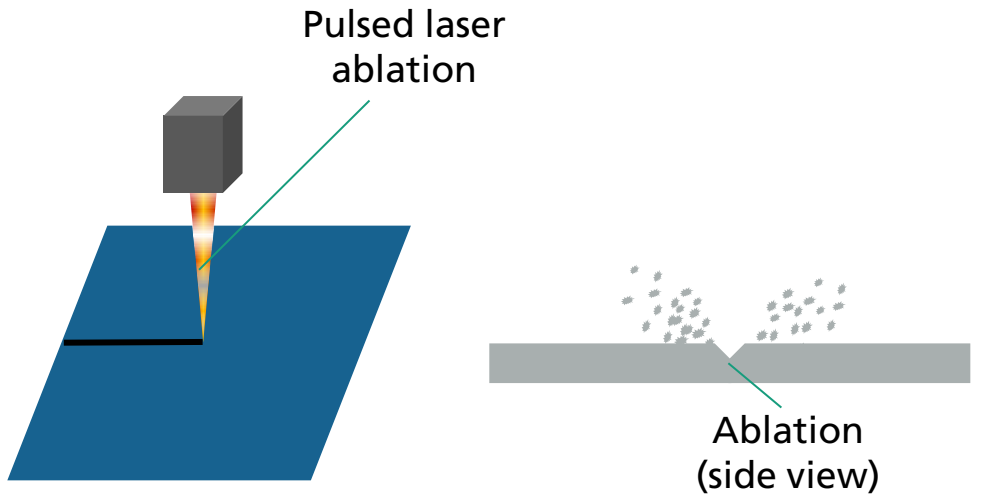
Separation Process
Comparison of Separation Processes

- Laser scribing mechanical cleaving (LSMC) "conventional" separation[1,2]:
  - Scribe by a pulsed laser over the whole separation path length **(ablation)**



[1] M. Oswald *et al., 28th EUPVSEC* (2013)
[2] F. Gérenton *et al., SolMat* (2020)

Separation Process
Comparison of Separation Processes

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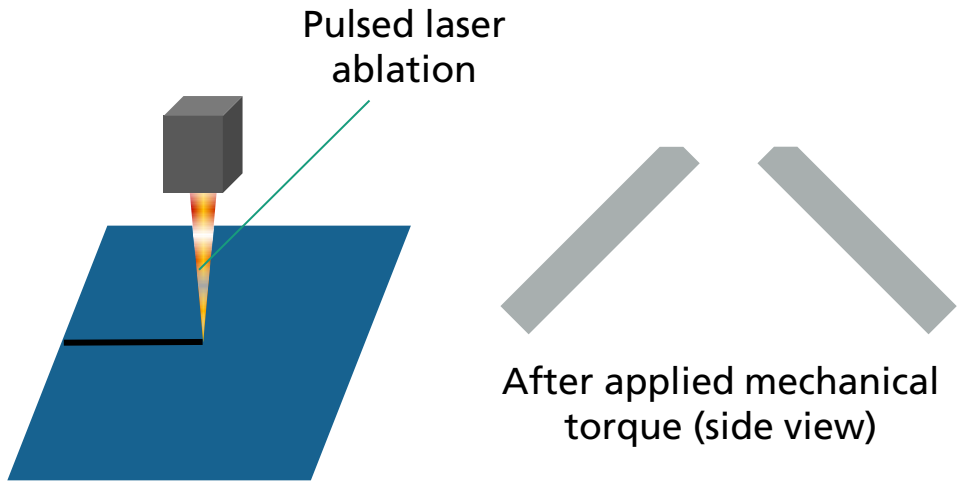
  - Mechanical cleaving **(breaking)**



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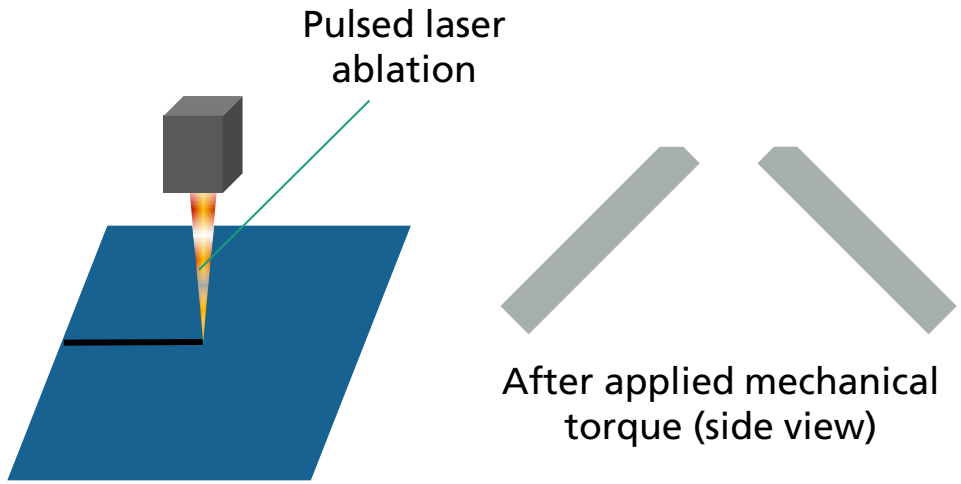

- Separation processes on PERC solar cells experimentally investigated

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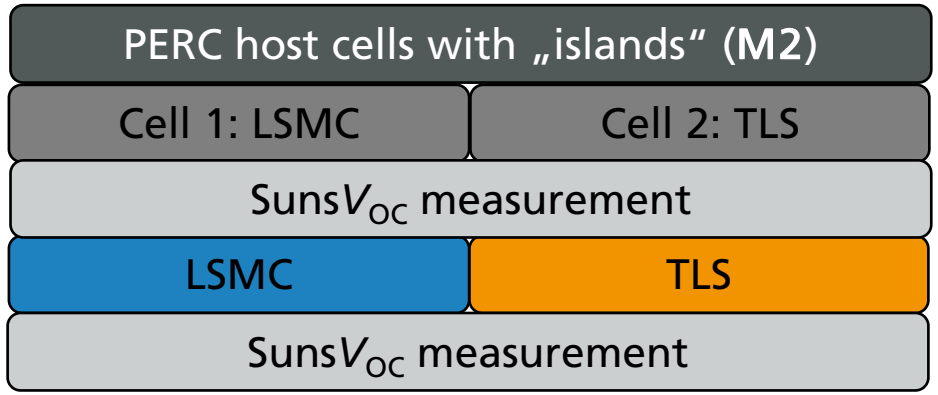
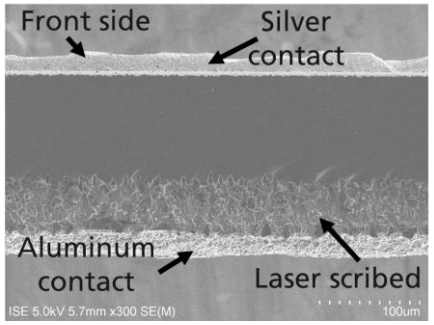
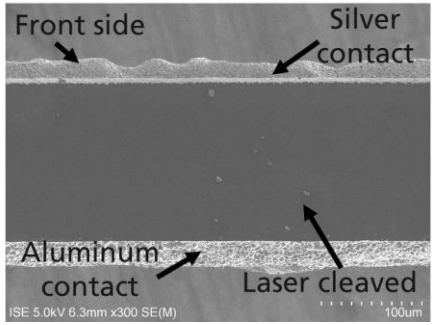
Separation Process Comparison
Small-sized PERC Solar Cells

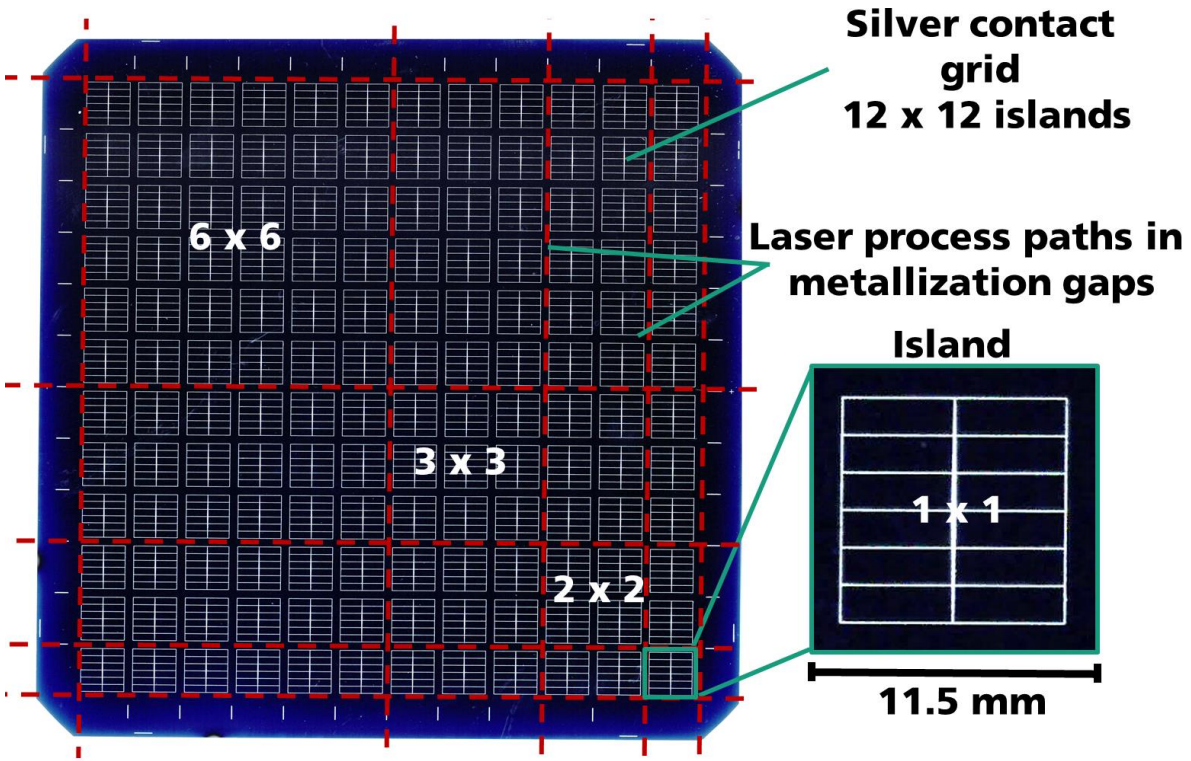
- Smaller cells → higher edge recombination impact



Separation from emitter-free side (rear side)

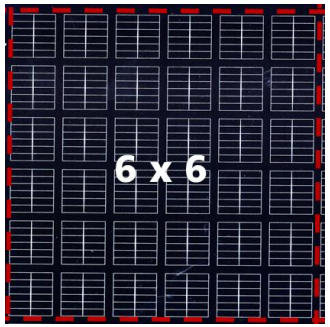


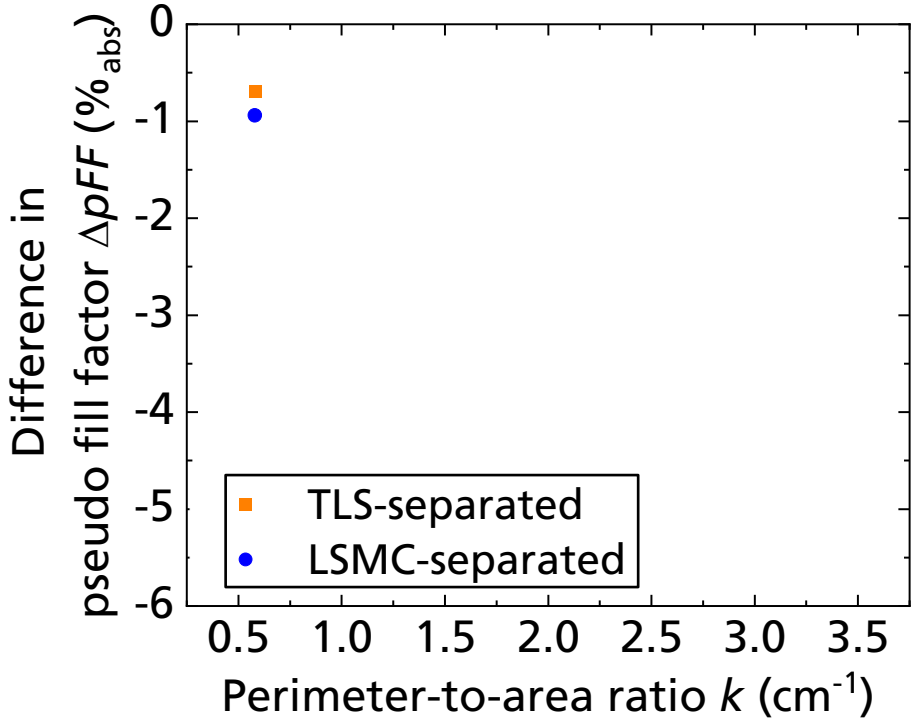




Separation Process Comparison
Small-sized PERC Solar Cells

$$k = \frac{\textit{Separated edge length}}{\textit{Area of separated cell}}$$





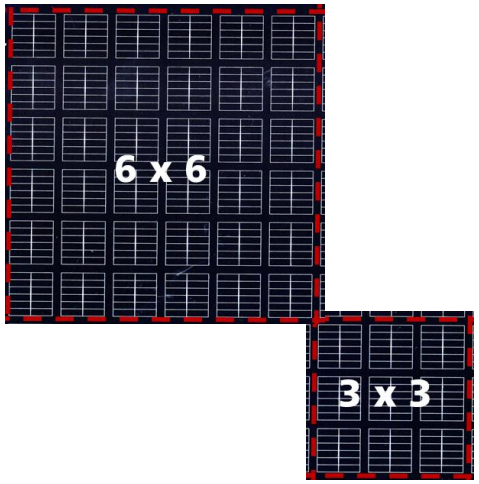
$\Delta pFF = pFF_a - pFF_b$

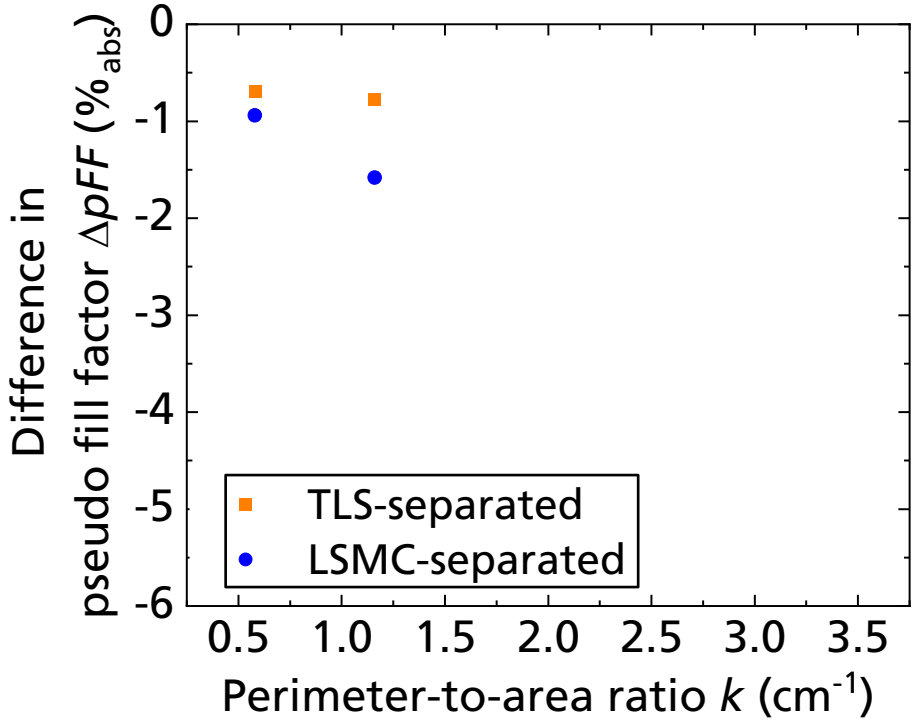
pFF_a: after separation

pFF_b: before separation

Separation Process Comparison
Small-sized PERC Solar Cells

$$k = \frac{\textit{Separated edge length}}{\textit{Area of separated cell}}$$





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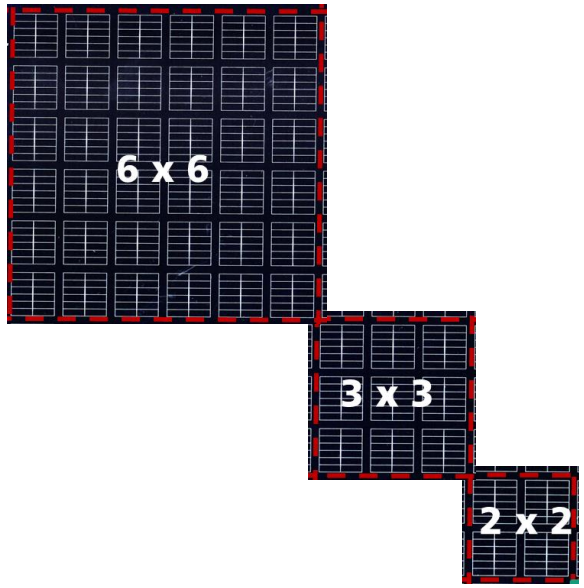

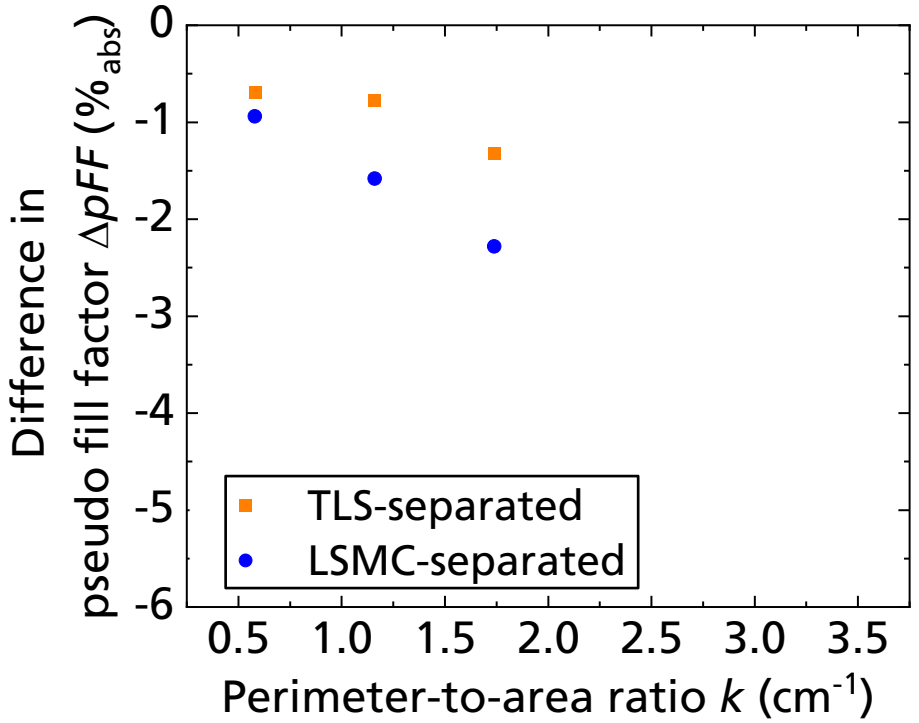

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Separation Process Comparison
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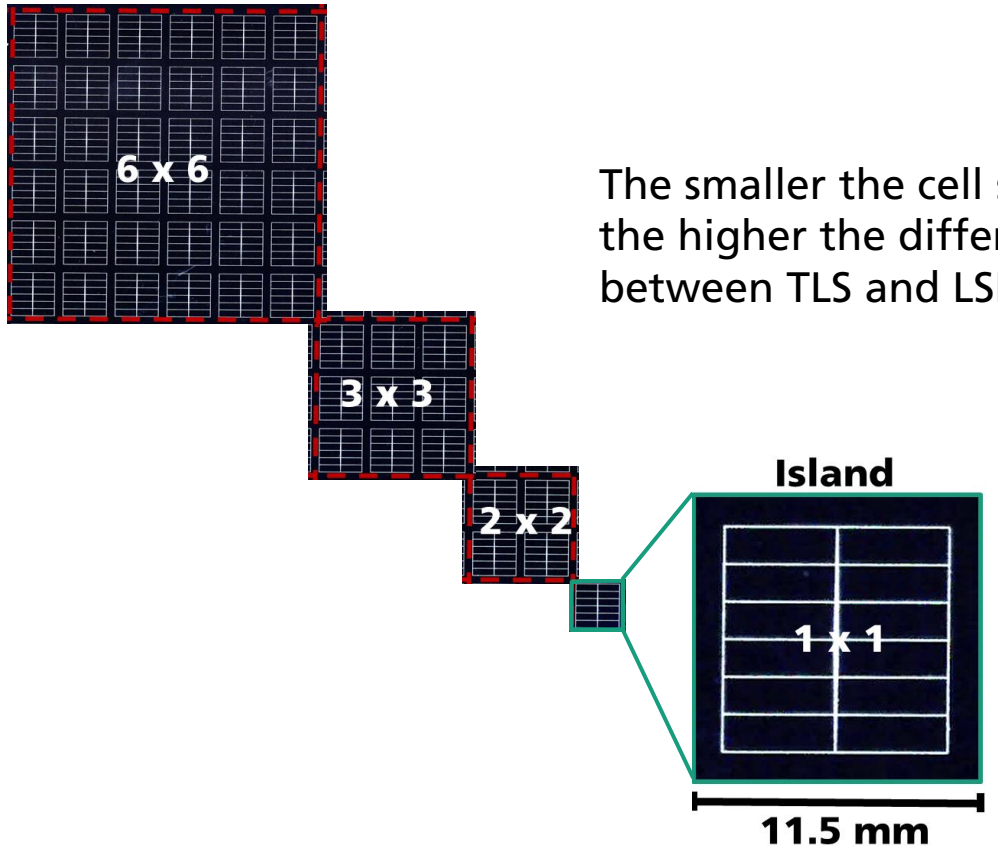
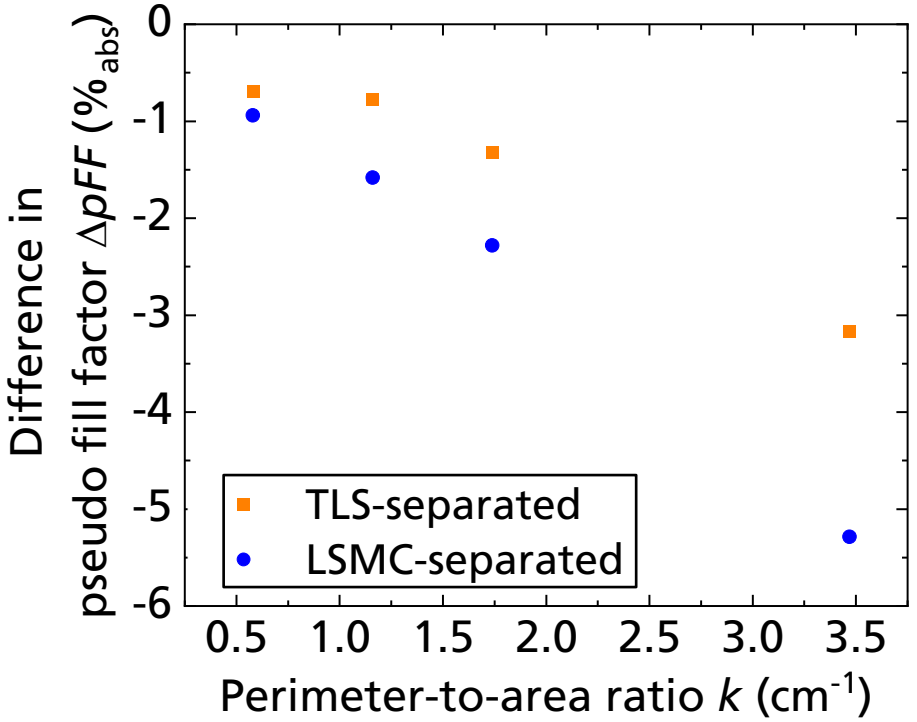


The smaller the cell size the higher the difference between TLS and LSMC



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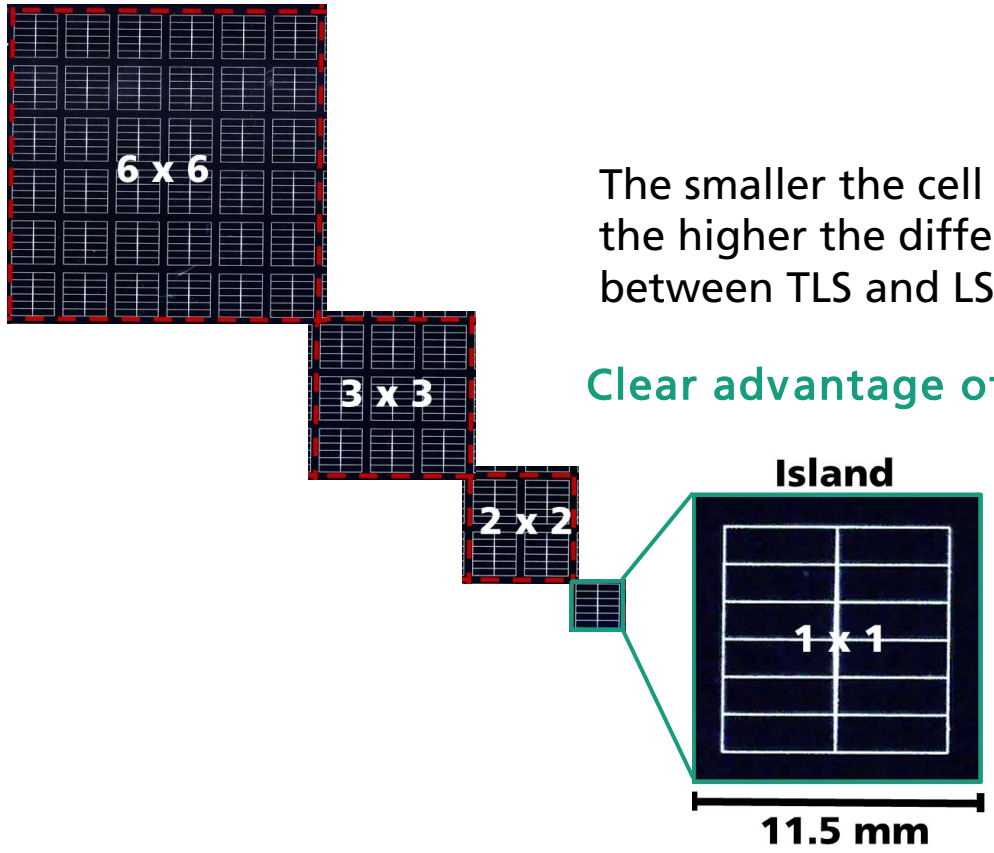
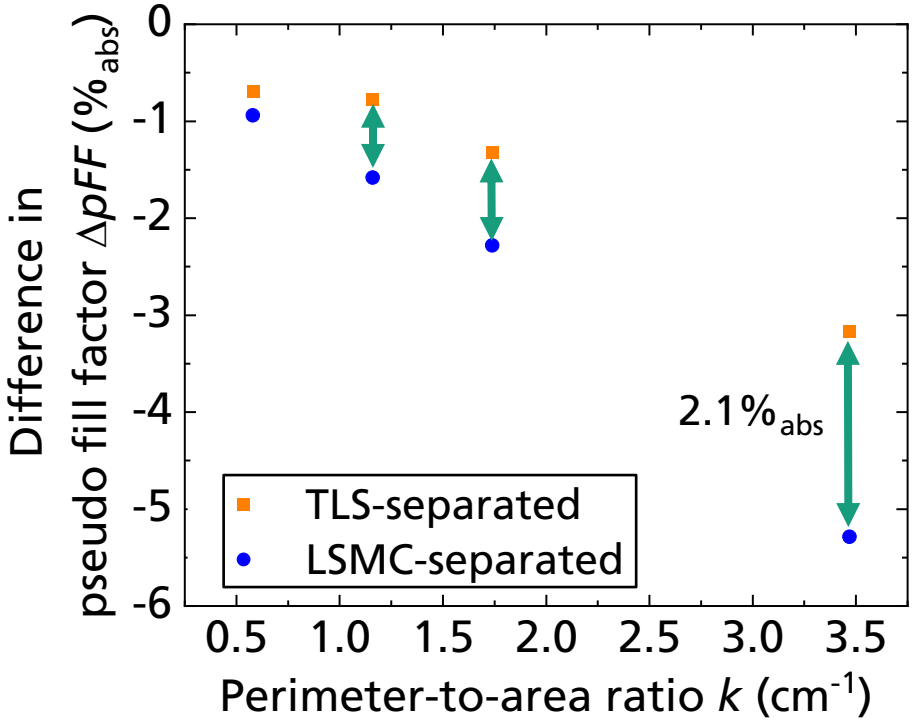
Separation Process Comparison
Small-sized PERC Solar Cells

$$k = \frac{\textit{Separated edge length}}{\textit{Area of separated cell}}$$



The smaller the cell size the higher the difference between TLS and LSMC

Clear advantage of TLS



$\Delta pFF = pFF_a - pFF_b$

pFF_a: after separation

pFF_b: before separation

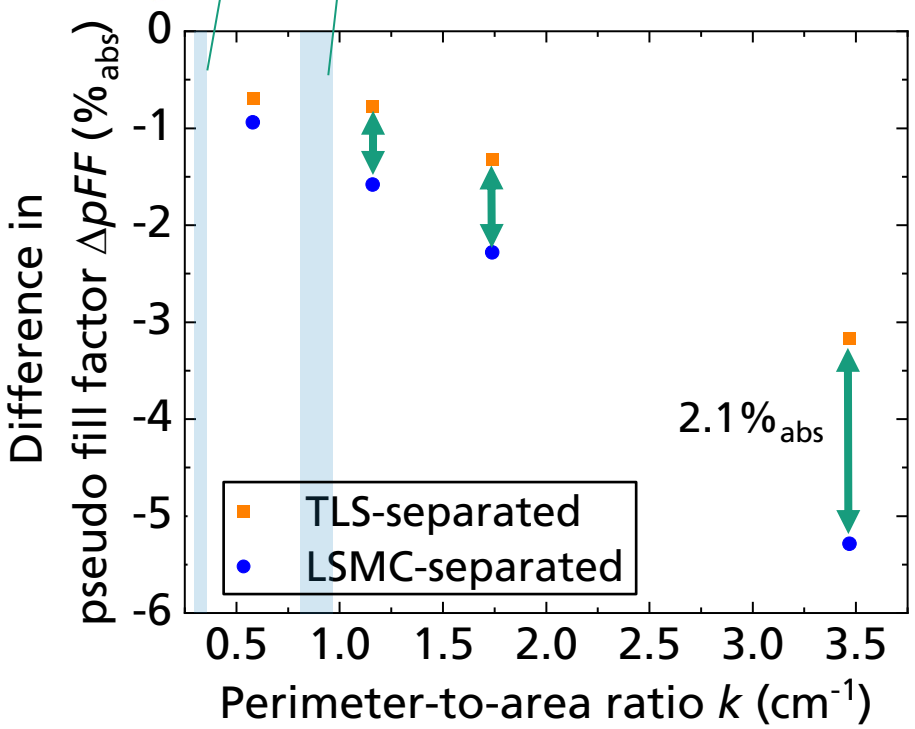
Separation Process Comparison
Small-sized PERC Solar Cells

- Considering the formats
  - M2 – M12 half cells
  - M2 – M12 shingle cells (1/6th middle shingles)

- **The smaller the separated cell size the more important is a defect poor edge**

- **Additional edge passivation is desired!**

$$k = \frac{\textit{Separated edge length}}{\textit{Area of separated cell}}$$



$\Delta pFF = pFF_a - pFF_b$

pFF_a: after separation

pFF_b: before separation

Approach

Passivated Edge Technology (PET)

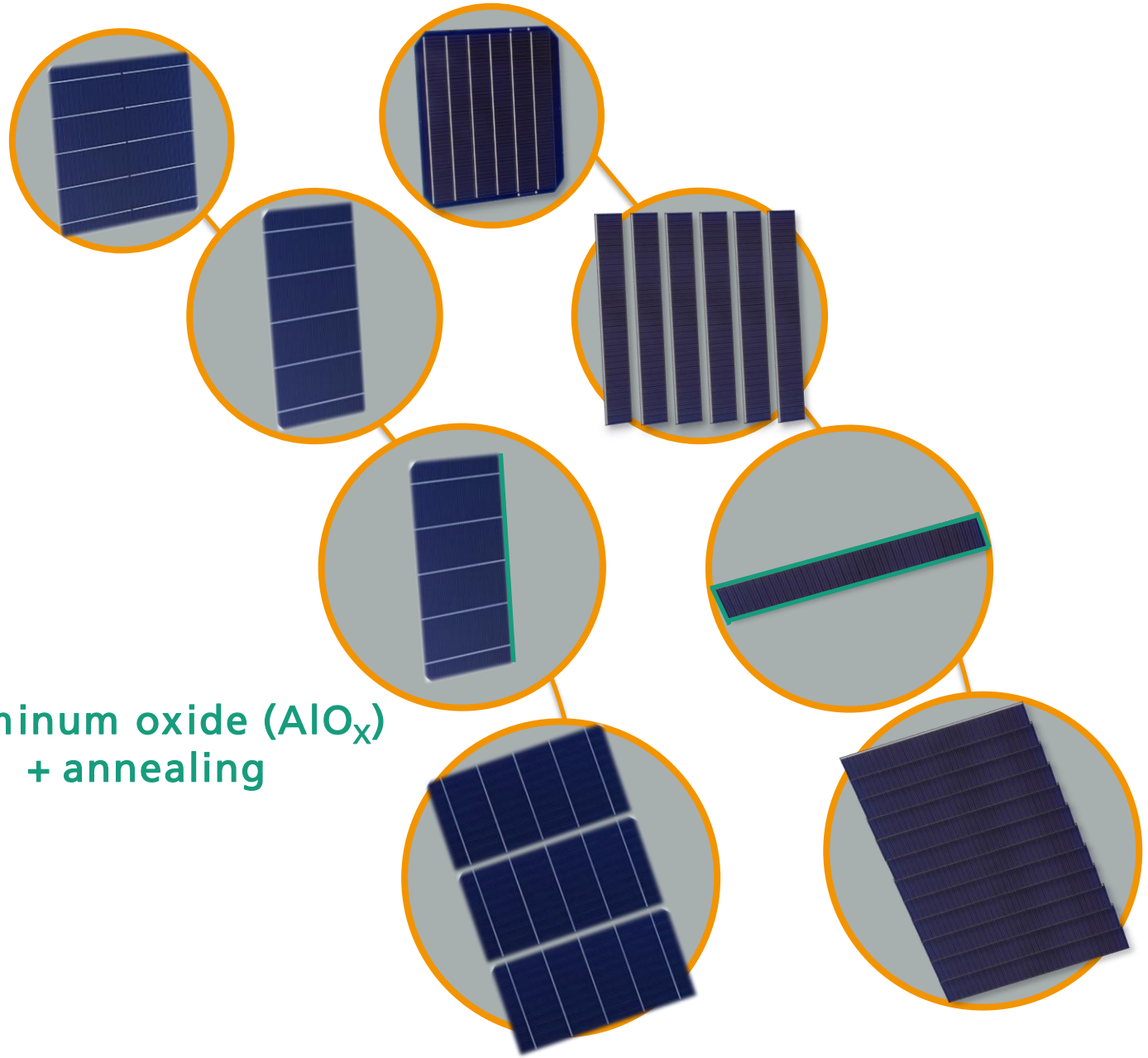
Full wafer-sized solar cells…
After contact formation

…separated
less current per cell

…edge passivation with Passivated Edge Technology (PET) *treatment*[1,2]

…interconnected into strings

Aluminum oxide (AlO_X) + annealing



[1] P. Baliozian *et al.*, *IEEE JPV* (2020)
[2] Patent granted (2020)

Passivated Edge Technology

Experiment – Lab Scale[1]

PERC Host cells

SunsV_{OC} measurement

Rear side LSMC | Rear side TLS

SunsV_{OC} measurement

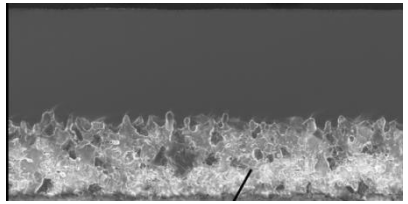
AlO_X deposition

SunsV_{OC} measurement

Annealing

SunsV_{OC} measurement

Host cells



LSMC TLS

14 nm w/o
As-deposited

14 nm w/o
Annealed

[1] P. Baliozian *et al. presented in IEEE PVSC* (2020)

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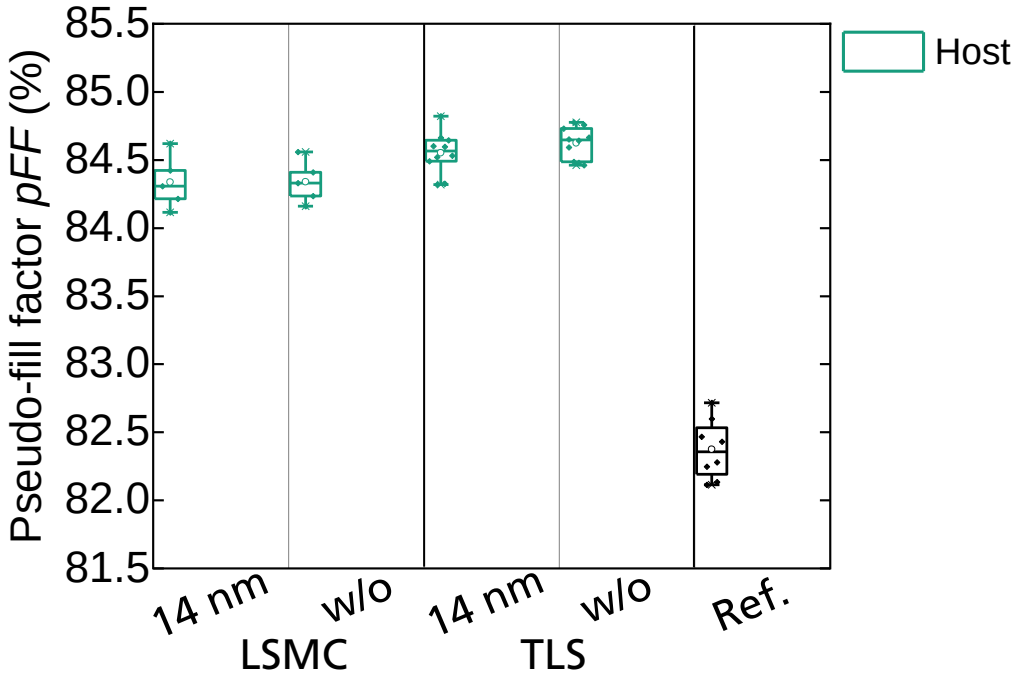
Results

SunsV_{OC} Measurements[1]

Host cells

SunsV_{OC} measurement

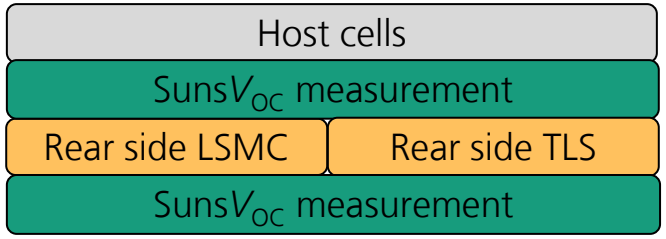
- Host cells measured and *pFF* values considered



[1] P. Baliozian *et al. presented in IEEE PVSC* (2020)

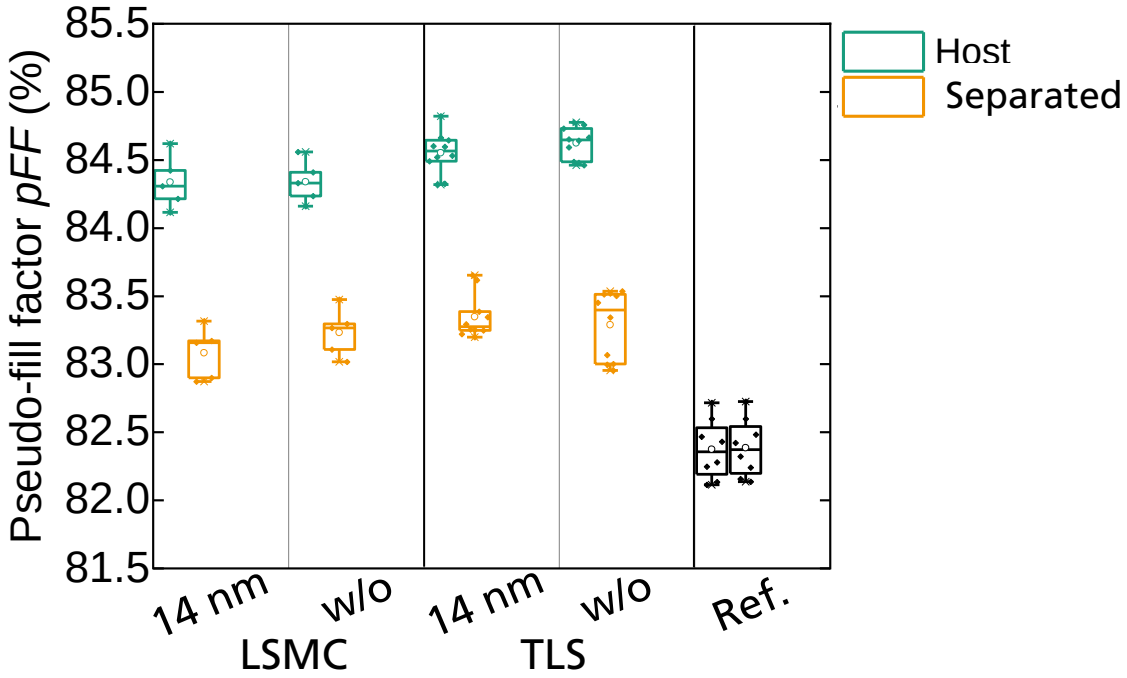
Results

SunsV_{OC} Measurements - Separation[1]



- Host cells measured and *pFF* values considered

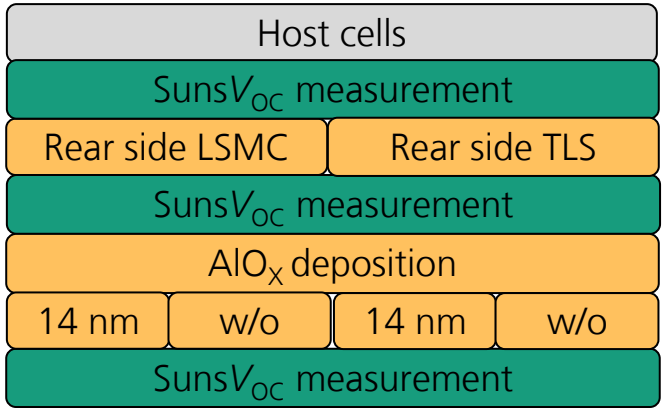
- Similar drops in *pFF* for TLS and LSMC processes



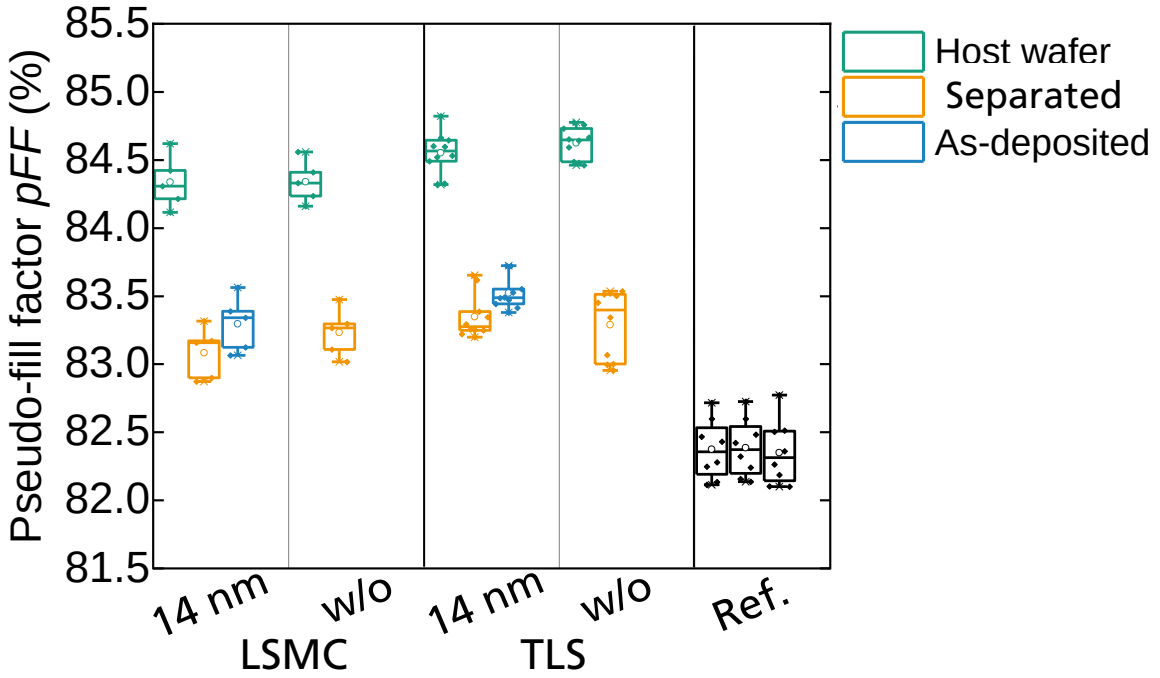
[1] P. Baliozian *et al. presented in IEEE PVSC* (2020)

Results

SunsV_{OC} Measurements - Deposition[1]



- Host cells measured and *pFF* values considered
- Similar drops in *pFF* for TLS and LSMC processes
- Minor increase due to deposition

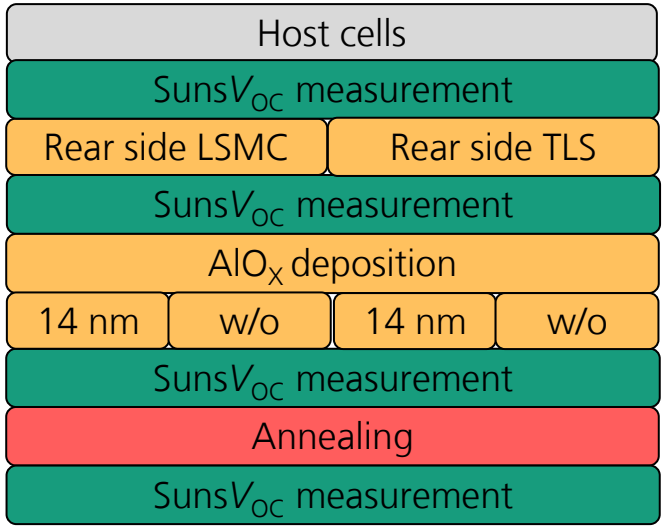


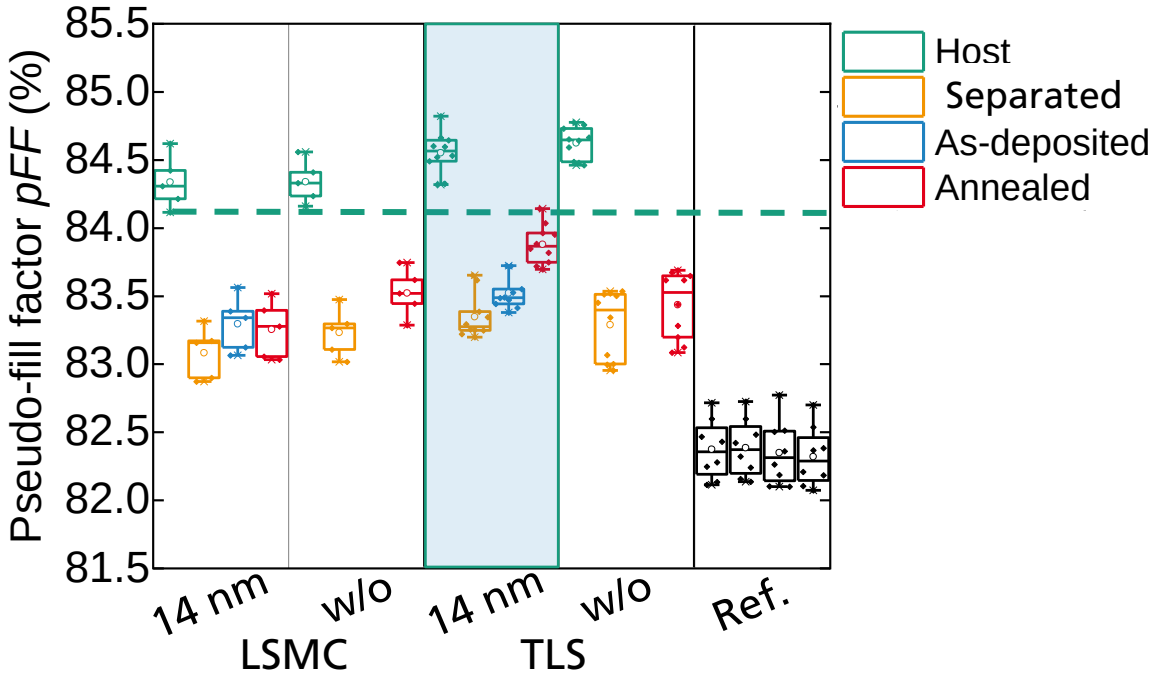
[1] P. Baliozian *et al. presented in IEEE PVSC* (2020)

Results

SunsV_{OC} Measurements – Annealing[1]

- Host cells measured and *pFF* values considered
- Similar drops in *pFF* for TLS and LSMC processes
- Minor increase due to deposition
- Combination of deposition and annealing of TLS-separated cells:
  - $\Delta pFF = +0.6\%_{abs}$
  - $50\%_{rel}$ regain (from separated state)





[1] P. Baliozian *et al. presented in IEEE PVSC* (2020)

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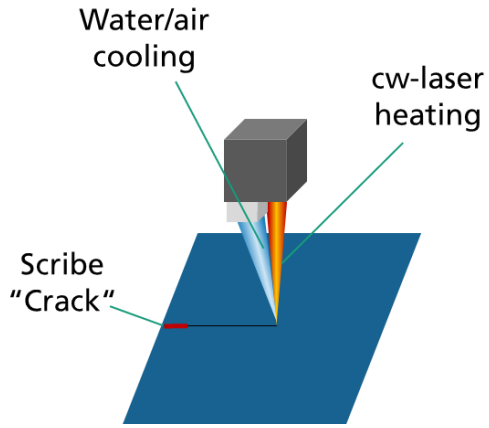
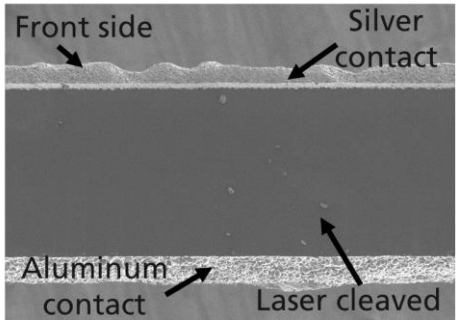
Summary

Thermal Laser Separation and Passivated Edge Technology



- Photoluminescence imaging used for TLS cleave process optimization
- Losses in open-circuit voltage V_{OC} and pseudo-fill factor *pFF* mainly attributed to creation of new edges
- Advantage of TLS in comparison to laser scribing and mechanical cleaving (LSMC)
- Post-metallization edge passivation
  "Passivated Edge Technology" (PET)
- Combination of TLS and PET:
  - Increase in *pFF* by $+0.6\%_{abs}$ ($50\%_{rel}$ regain from separated state)
  - Low damage separation required for an effective edge passivation



Acknowledgments
Thanks to…

- Fraunhofer ISE colleagues
- The German Federal Ministry for Economic Affairs and Energy for funding **"PV-BAT400"** (contract no. 0324145)

Puzant Baliozian | *Production Technology: Structuring & Metallization*

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