PRECISE SELECTIVE DOPING AND METALLIZATION FOR NEXT-GENERATION PERC TECHNOLOGY

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[1]Sun Chemical (UK)

[2]Meyer Burger (NL) B.V.

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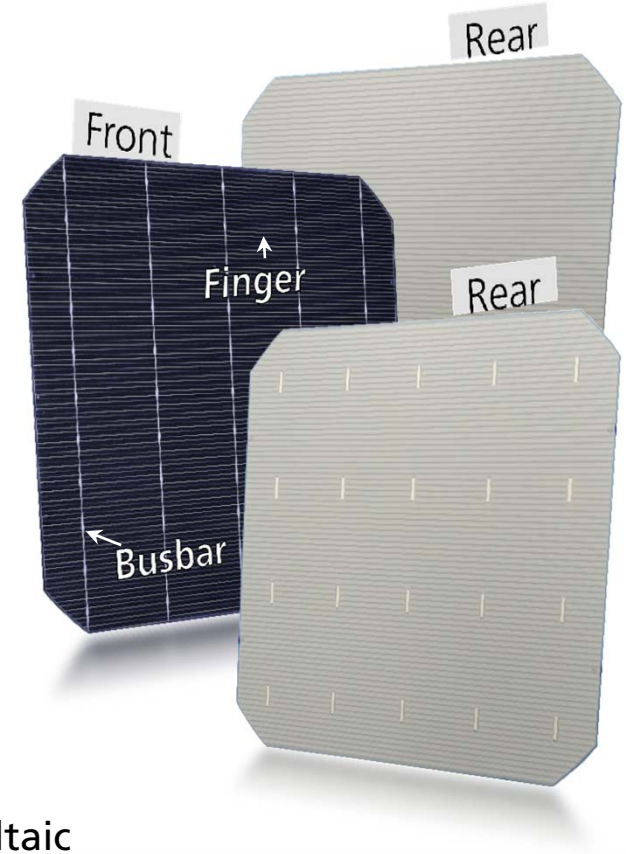
AGENDA

- Motivation
  - PERC's roadmap according to ISE
  - ITRPV predictions
- Approach
  - PERC base line
  - Precise, congruent patterning
- Application
  - Selective emitter PERC
  - Bifacial cells
- Conclusions



ITRPV: International Technology Roadmap for Photovoltaic

Motivation

PERC's roadmap according to ISE

- 7-step program to 240 W/m² *
  - 1: Fine, high aspect ratio front contacts
  - **2: No-overlap selective emitters**
  - 3: Low-cost, high quality material
  - 4: Increased productivity
  - **5: Bifaciality**
  - 6: Bifacial shingled cells with passivated edge
  - 7: Introduction of passivated contacts

R. Preu et at., SNEC 2018

*Bifacial illumination: G_{front} = 1000 W/m², G_{rear} = 100 W/m²

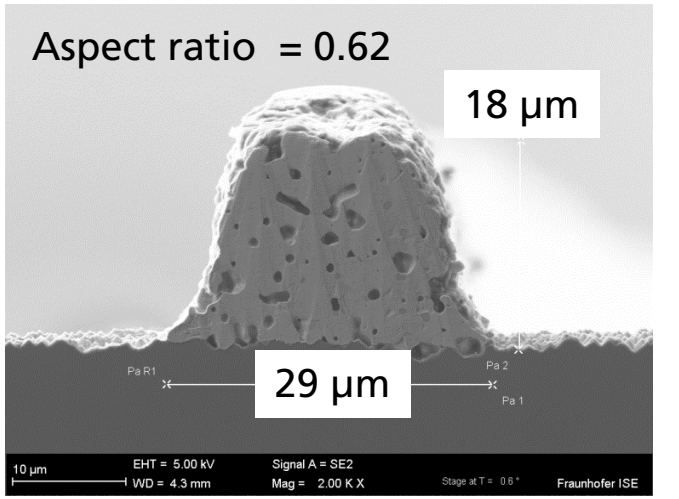
Motivation

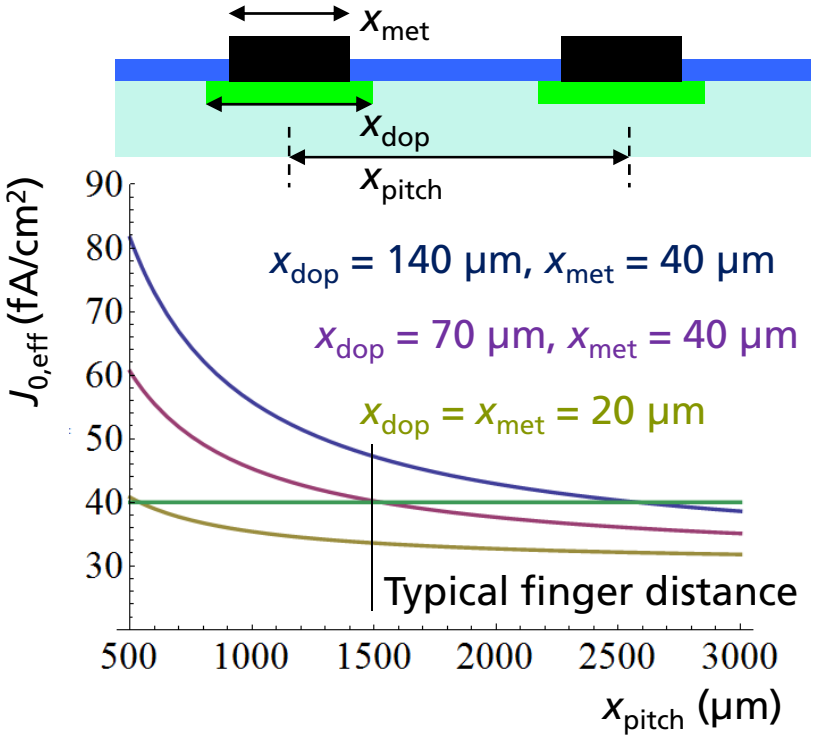
ITRPV predictions for 2029

- Feature size target
  x_{met} below 20 µm

- Effective dark saturation current density target per side
  $J_{0,eff}$ below 40 fA/cm²

- ➢ Precision enables ITRPV predictions
- ➢ Max. alignment tolerance of ±15 µm





ITRPV, 2018 Results, Tenth Edition, March 2019

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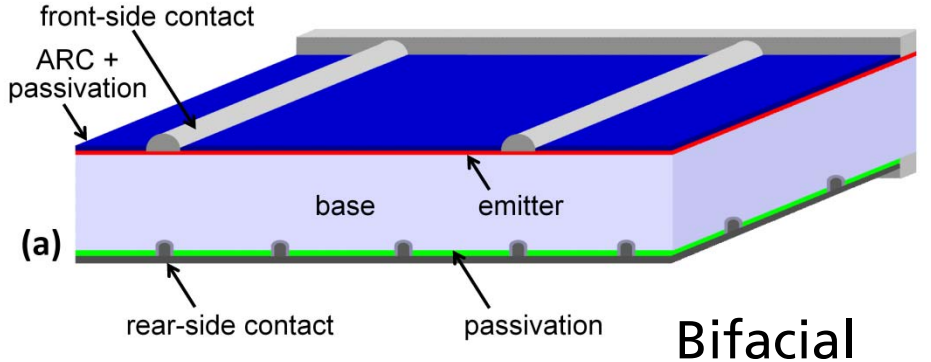
Motivation

ITRPV predictions for 2029

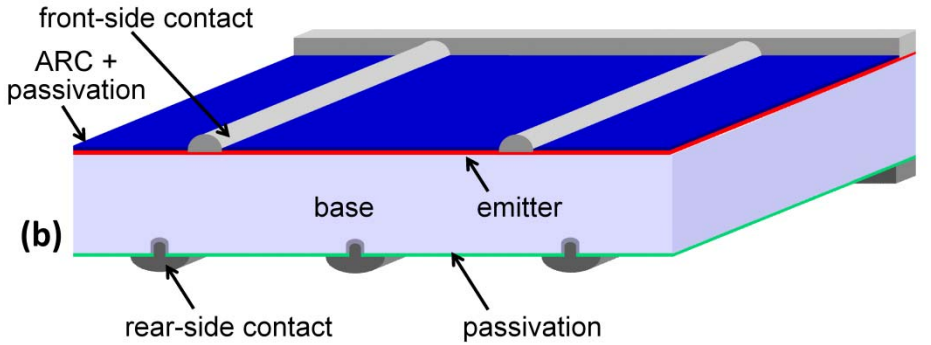
- Bifacial cells enable
  - Collection of light from both solar cell sides
  - Additional **yield by 10 - 40% [1-3]**
- Bifacial cells will gain market share
  - 15% in 2019
  - **60% in 2029**

➢ Even more patterning

Monofacial



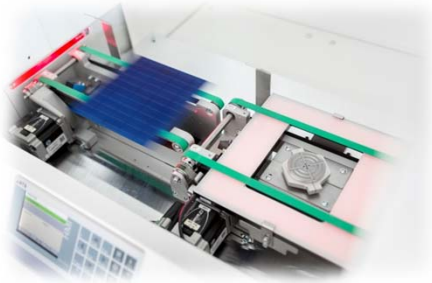
Bifacial

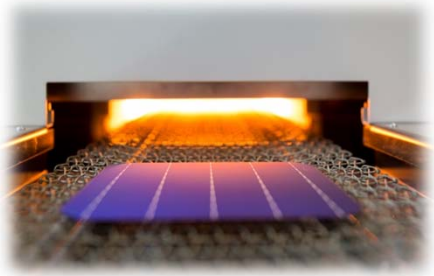


[1] L. Podlowski et al., Bifi workshop, 2017;
[2] N. Eisenberg, R. Kopecek, V. Fakhfouri et al., PV-tech.org, 2017;
[3] A. Flores et al., Taiyang News, 2017;

Approach
PERC base line process

- Industrial PERC solar cells processed in two separate pilot-lines
  - Front-End (no metal)
  - Back-End
- Efficiency of **21.6 %**
- Evaluation of
  - Machines and Components
  - Materials like **solar cell precursors**

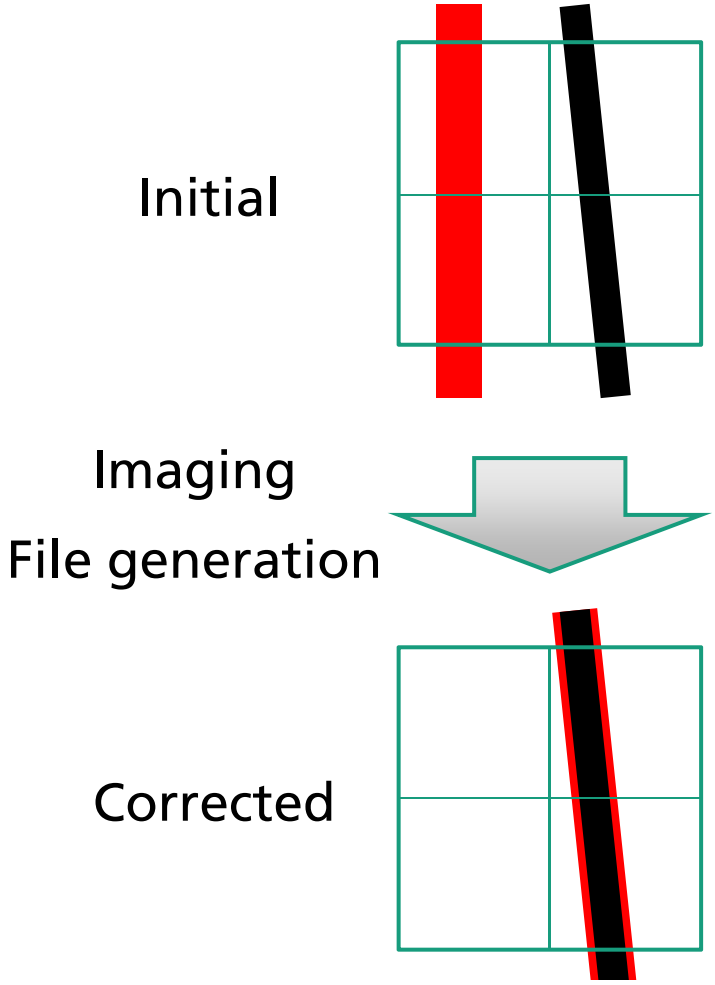




Approach

Precise, congruent patterning

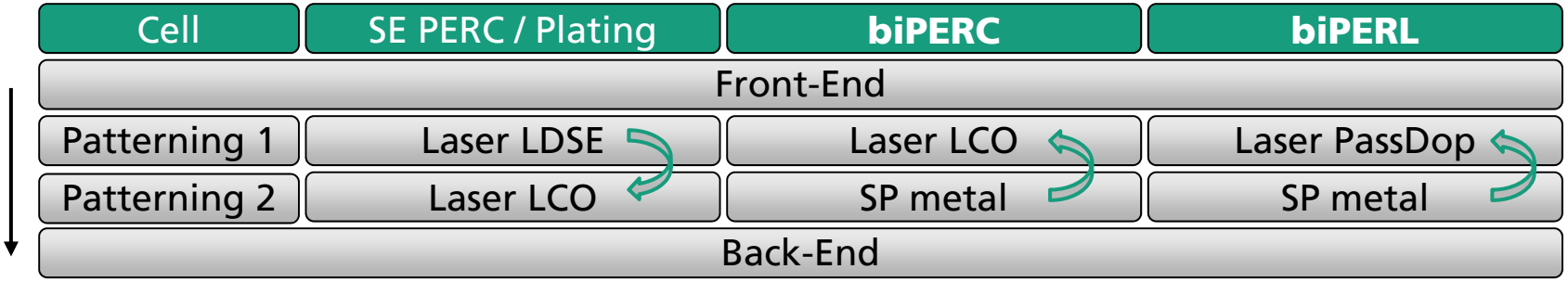
- Digital file generation based on e.g. screen-printed pattern
- Procedure
  - Fabrication of test samples
  - Imaging, $r_{x,y}$ = **5 µm**
    - Shape determination
    - Offset determination
      - Typ. max. offset ± 50 µm
  - Shape-congruent file generation incl. Offset (algorithm)
  - Vision: AOI meets file generation



AOI: Automated Optical Inspection

Approach
Industrial application

- Patterning process 2 and 1 can be adapted to each other
- Patterning process 1 can be adapted to process 2 and the processes are directly in a row
- ➢ Potential industrial PERC upgrades



- R&D option: SE PERC; inkjet for ink&etch doping and screen printing for metallization;

LDSE: Laser-diffused sel. Emitter; LCO: Laser contact opening; SP: Screen printing;
SE: Selective emitter;

Application I (R&D)
Selective emitter PERC

Screen-printed metal on ink&etch doping

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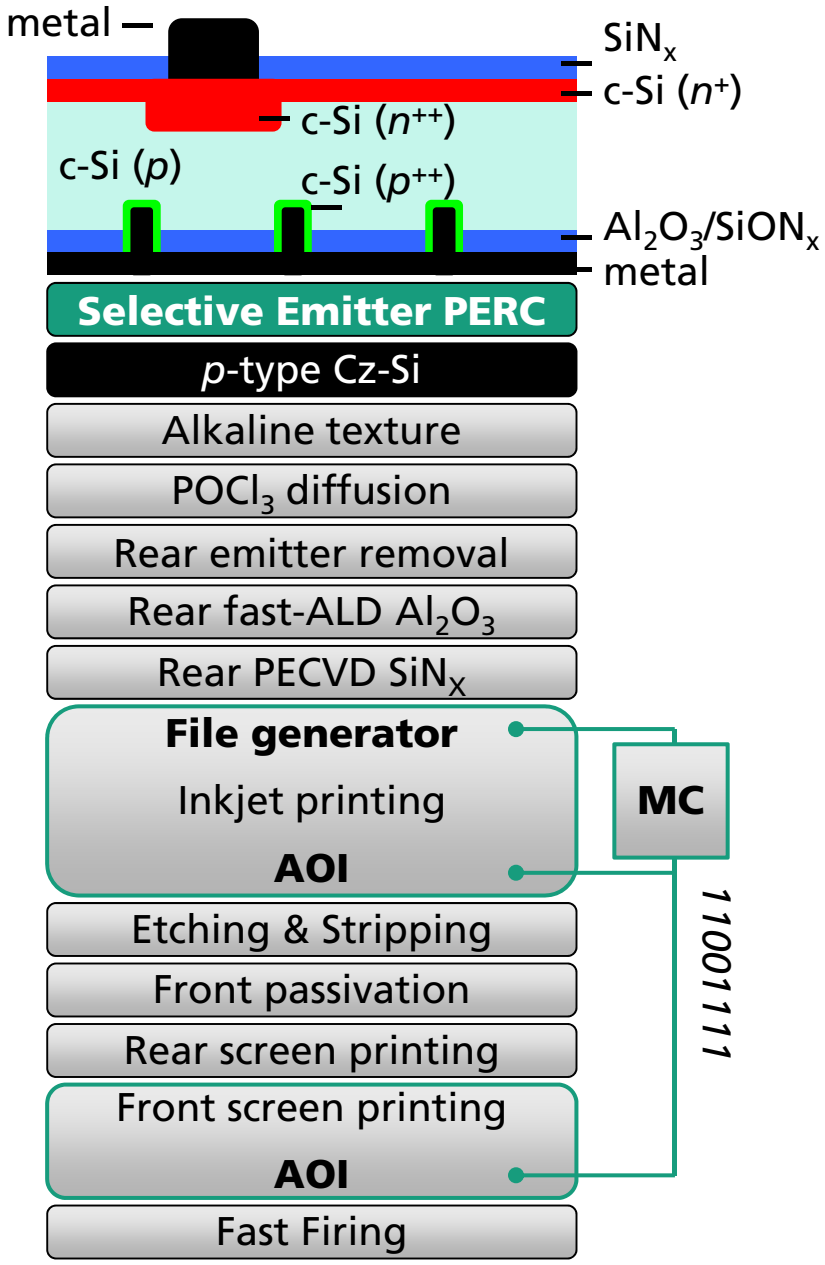
Selective Emitter PERC
Patterning

- Doping patterning
  - Diffusion
  - Ink&etch of c-Si (n^{++})
- Metal application
  - Screen printing
  - Alternatives at ISE
    - Rotational printing
      - ➢ Flexo and Rotational SP
    - Dispensing

MC: Microcontroller

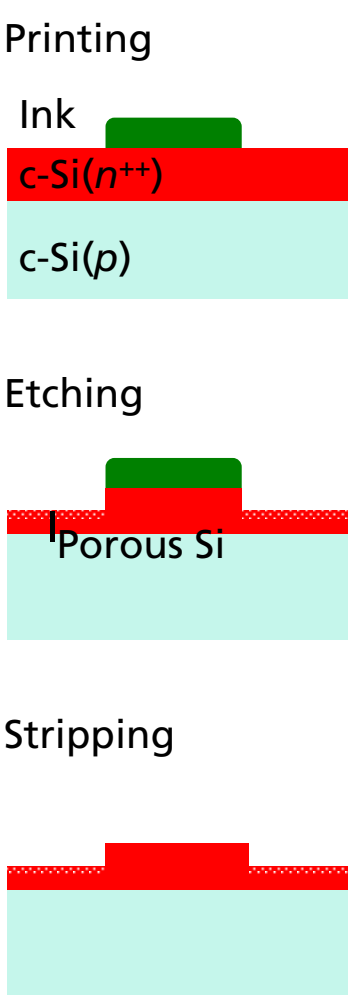


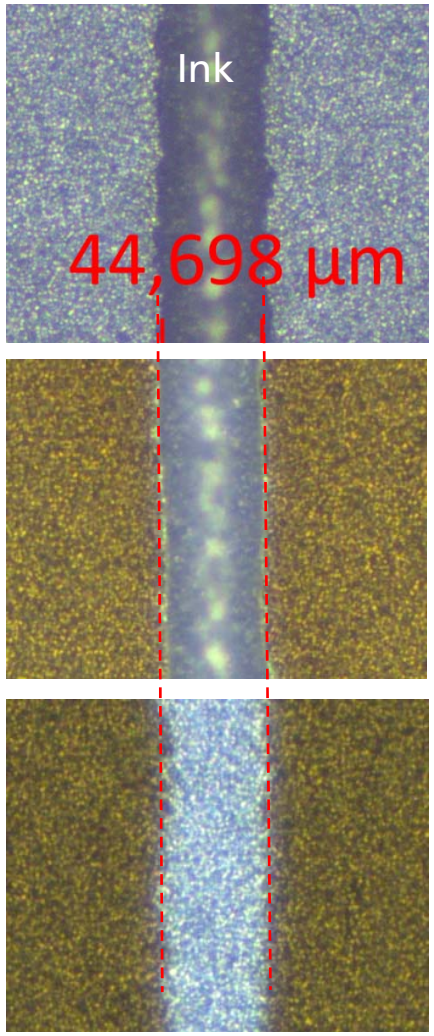
Selective Emitter PERC

Feature size of c-Si(n^{++})

- Technique
  - Inkjet of wax
  - Selective etching of silicon
  - Stripping and cleaning

- No underetching detected
- Feature size of c-Si(n^{++}) equals jetted lines
- ➢ Minimum feature size **below 30 µm**





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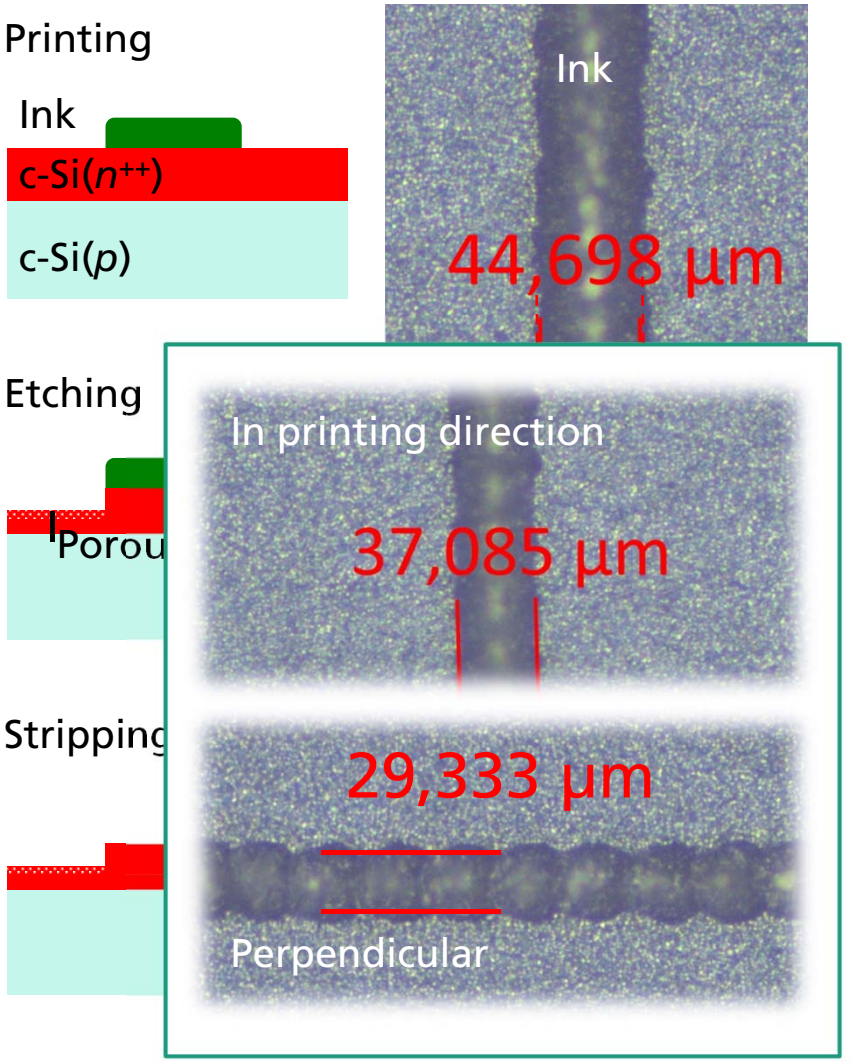

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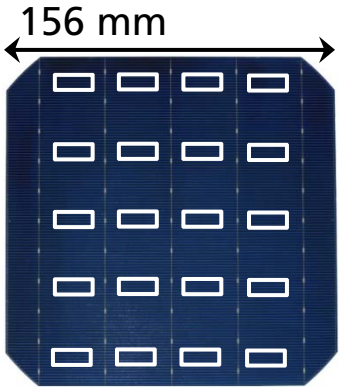
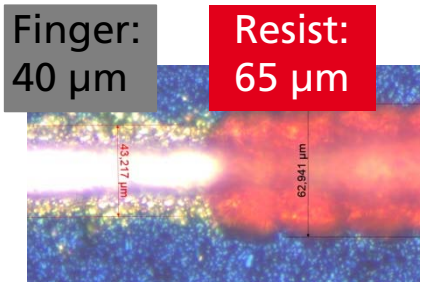
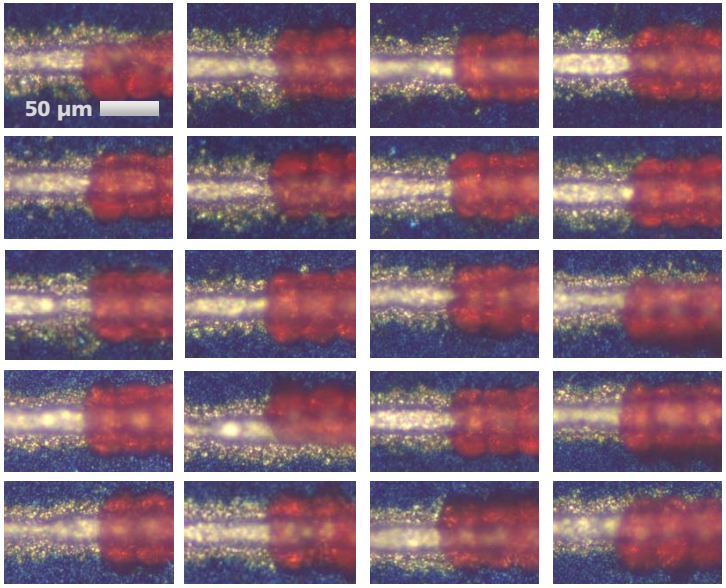
Selective Emitter PERC

Aligment precision

- Method
  - Screen printing of fingers
  - Inkjet printing of **adapted pattern** incl. **interrupted lines** for vizualization
  - Microscopy of around 1000 positions per wafer
- Result
- ➢ Alignment accuracy **below ±15 µm**







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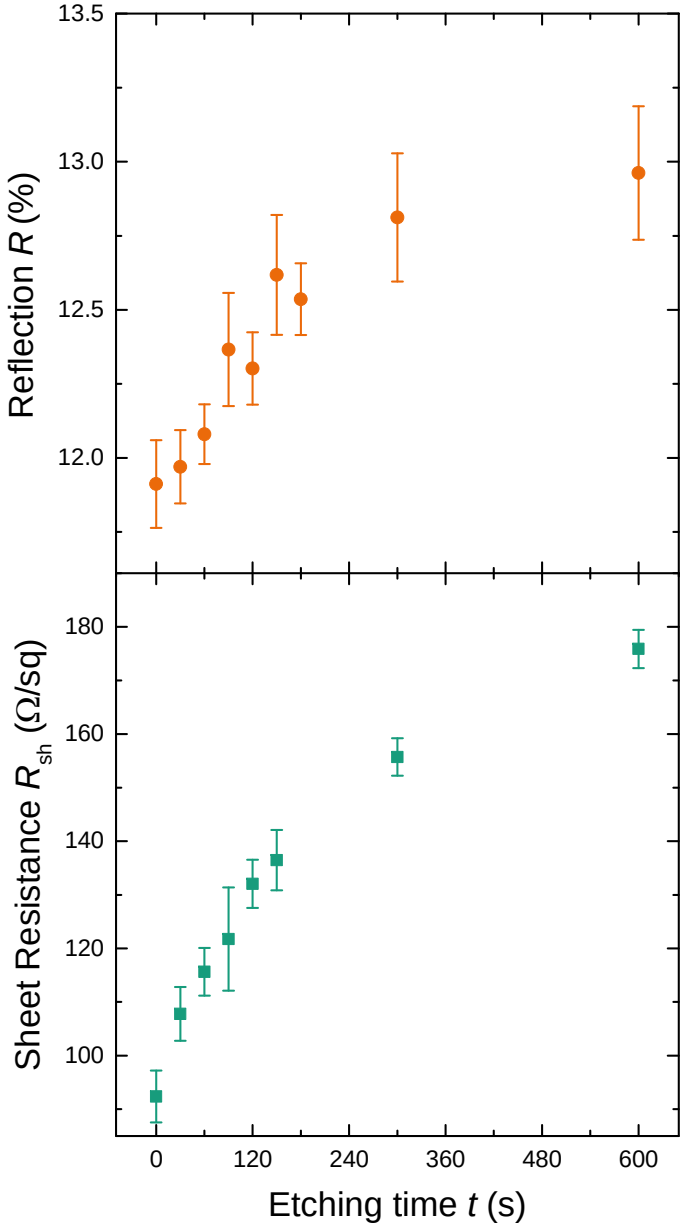
Selective Emitter PERC

Reflection and sheet resistance

- Sheet resistance R_{sh} adjustable with etching time
- Minor increase in reflection due to rounding of pyramids' tips
- **Trade-off** between resistive and recombination losses at **R_{sh} = 120 Ω/sq**



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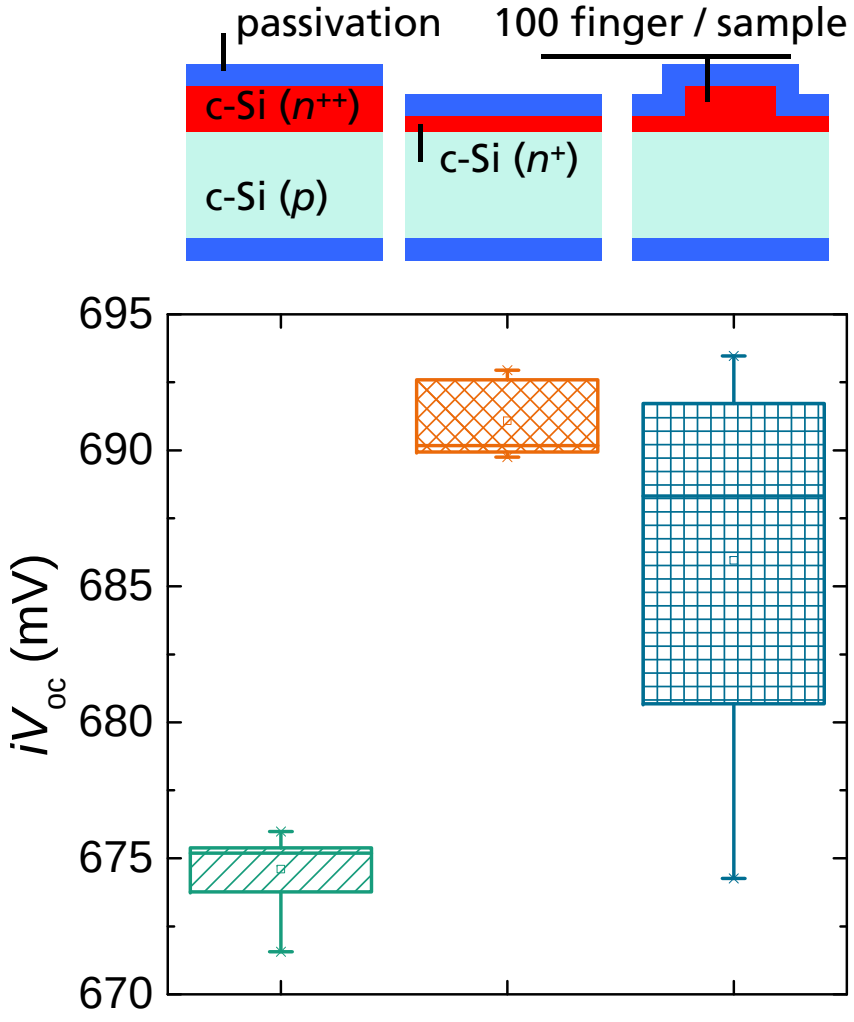
Selective Emitter PERC
Recombination

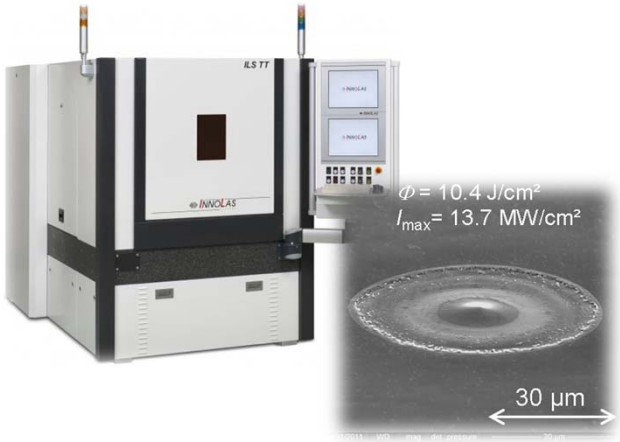
- Evaluation of recombination by QSSPC and unsymmetrical sampling
- Silicon etching improves implied open circuit voltage **i V_{oc}** by around **20 mV**
- Selective silicon etching leads to a decrease in homogeneity
- ➢ Interaction between ink and etching media assumed



QSSPC: Quasy steady state photo conductance

Application II (Industry)
Bifacial cells

Screen-printed metal on laser-induced doping (pPassDop) and Laser Contact Opening (LCO)



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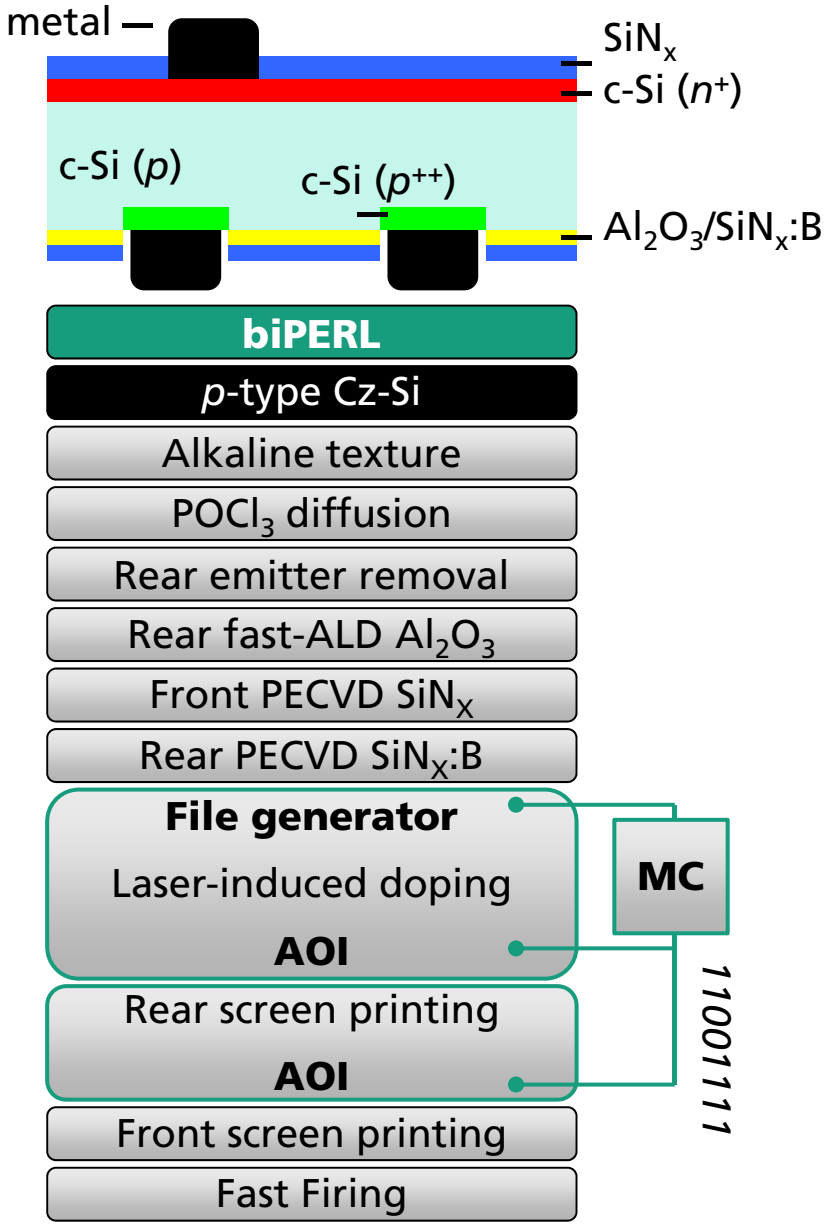
Bifacial PERL
Patterning

- Compatible with existing cell fabs
- Laser processing and screen printing **in a row**
  - ➢ Compatible with hazardous failure of screen printers

- Doping patterning
  - ➢ ***pPassDop***
    - Deposition of Al_2O_3/SiN_x:B
    - Laser-induced Al/B doping



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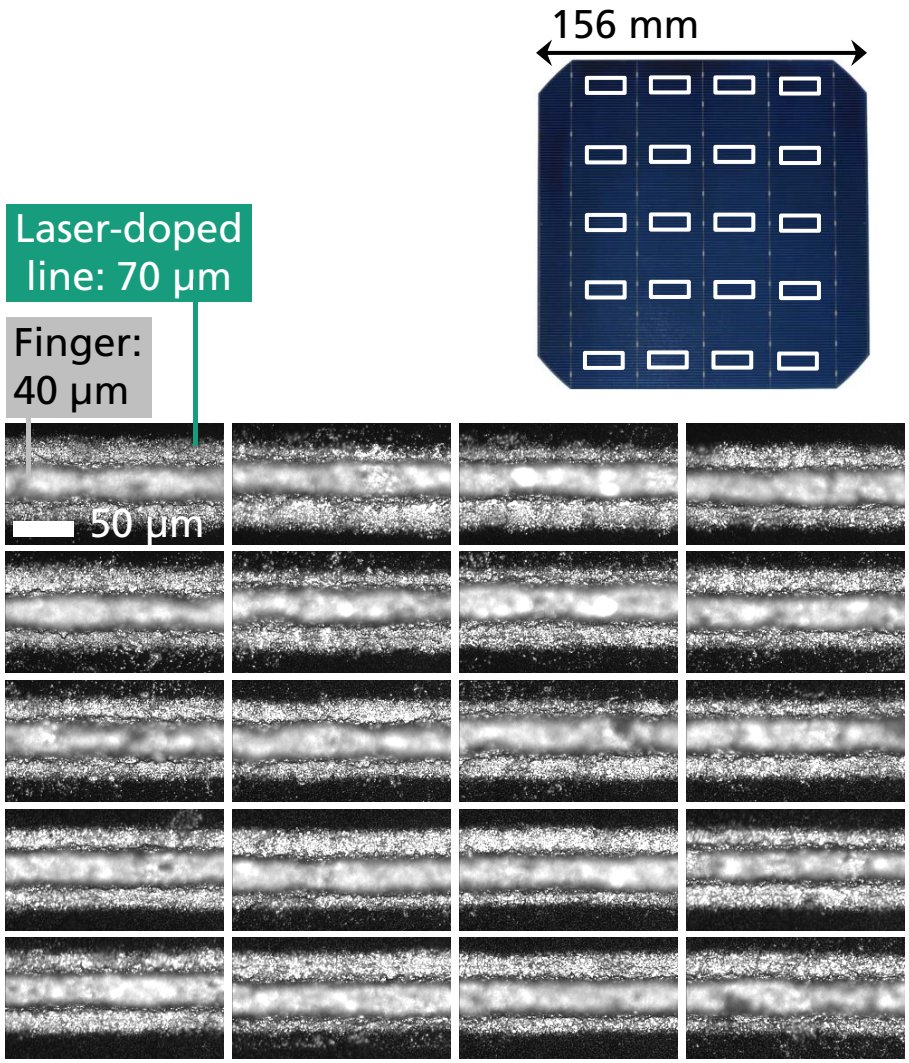

E. Lohmüller et al., WCPEC, 2018

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Solar cell results

Type	Prec.	V_{OC} (mV)	J_{SC} (mA/cm²)	*FF* (%)	η_{front} (%)	η_{rear} (%)	β (%)	p_{out}* (mW/cm²)
monoPERC	ISE	667	40.2	80.7	21.6			21.6
biPERL [1]	ISE	651	39.2	79.9	20.4	18.0	88	22.2

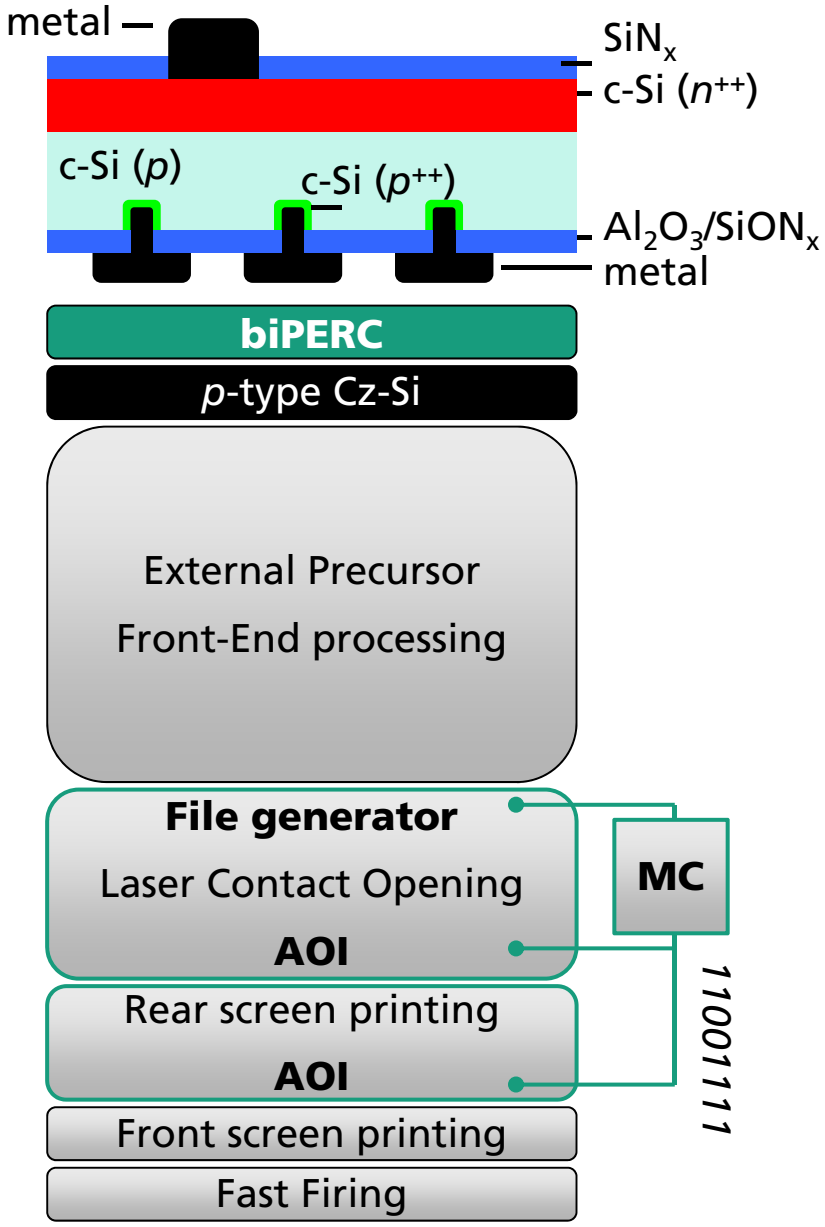
*p_{out} for G_{front} = 100 mW/cm² (STC) and G_{rear} = 10 mW/cm²;

Conversion efficiencies measured on a black chuck;

[1] E. Lohmüller et al., WCPEC, 2018

Bifacial PERC
Patterning

- LCO patterning
  - ➢ Laser processing
- Metal application
  - Screen printing
  - Al Paste (not firing-through)
- Contact fomation
  - Fast Firing
  - Al-Si alloying



Toyo Aluminium K.K.

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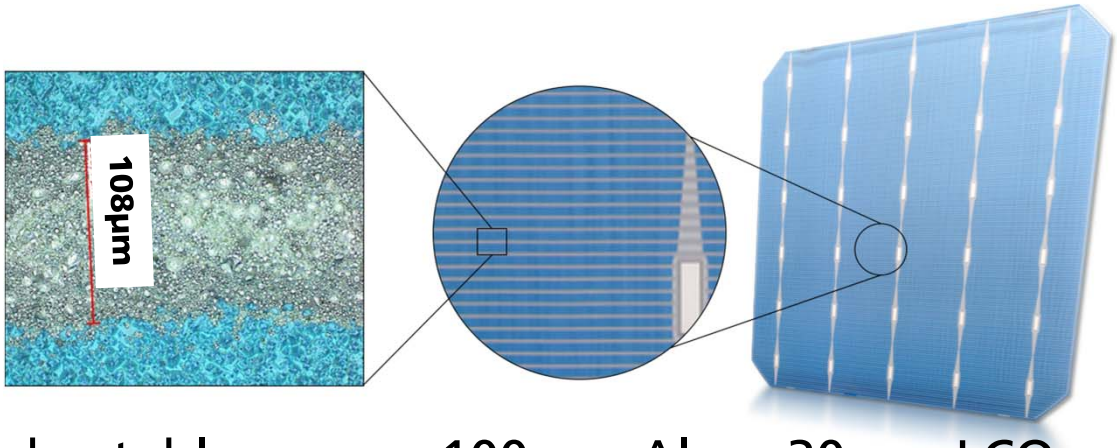
Solar cell results



- Generally: method works stable on e.g. 100 µm Al on 30 µm LCO

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biPERC [2]	Yes	674	39.7	80.0	21.4	12.6	59	**22.7**

*p_{out} for G_{front} = 100 mW/cm² (STC) and $\boldsymbol{G_{rear}}$ **= 10 mW/cm²**;

Conversion efficiencies measured on a black chuck;

[1] E. Lohmüller et al., WCPEC, 2018; [2] T. Fellmeth et al., PV-SEC, 2017;

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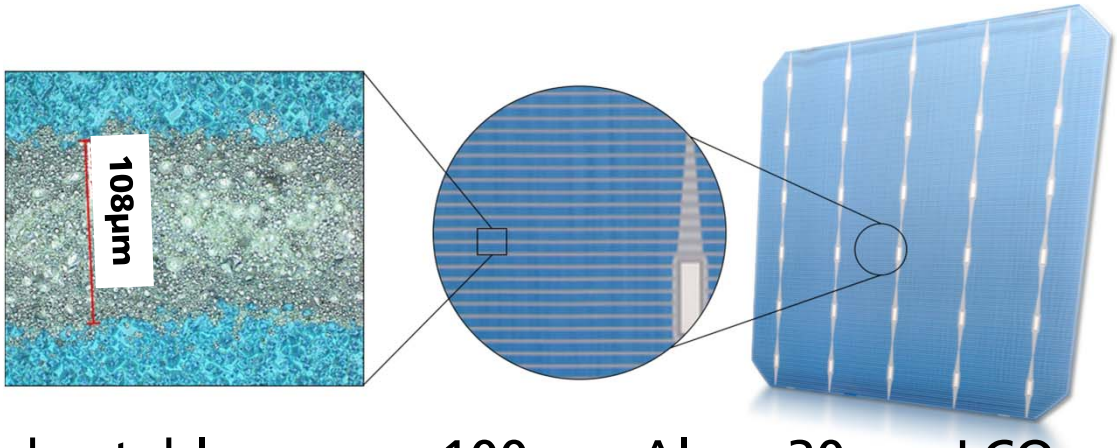
Solar cell results



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biPERL [1]	ISE	651	39.2	79.9	20.4	18.0	88	**24.0**
biPERC [2]	Yes	674	39.7	80.0	21.4	12.6	59	23.9

*p_{out} for G_{front} = 100 mW/cm² (STC) and $\boldsymbol{G_{rear}}$ **= 20 mW/cm²**;

Conversion efficiencies measured on a black chuck;

[1] E. Lohmüller et al., WCPEC, 2018; [2] T. Fellmeth et al., PV-SEC, 2017;

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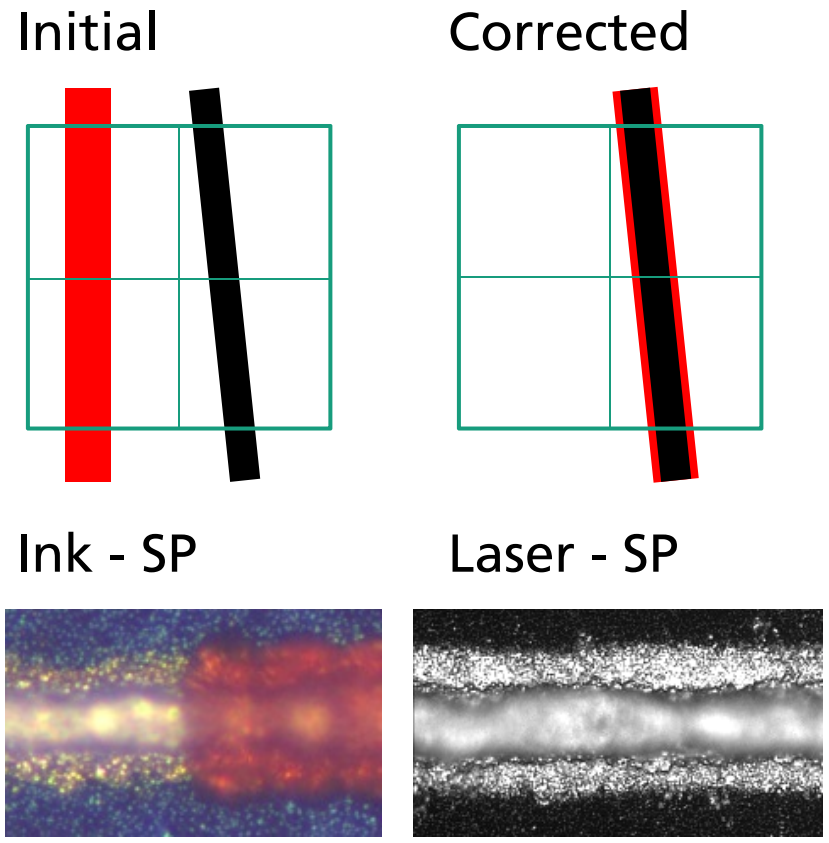
Conclusion

- Digital method established for precise, shape-congruent patterning
  - Scalable with AOI
- High alignment accuracy of ±15 µm between different patterning methods



- Successful process integration
  - biPERL (*p*-type)
  - biPERC (*p*-type)

Acknowledgement

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- SOLAR-ERA.NET for funding within the project
  - PEarl (contract no. 0324222)

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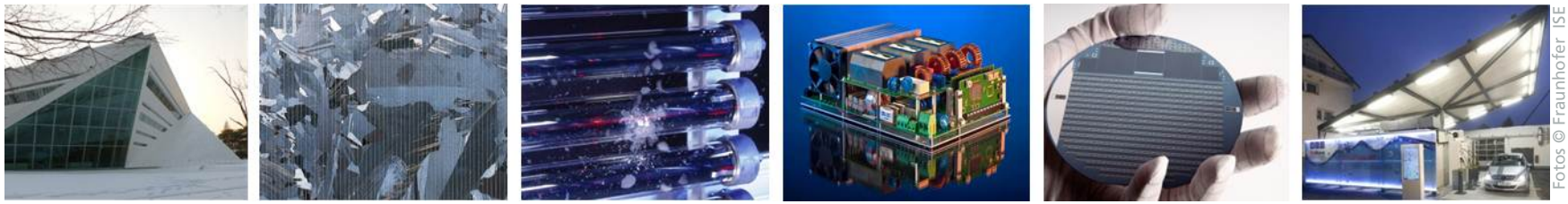
Thank you for your Attention!



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