IMPACT OF FIRING TEMPERATURE PROFILES ON LOCAL BSF FORMATION IN PERC SOLAR CELLS

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Konstanz, 03.05.2016

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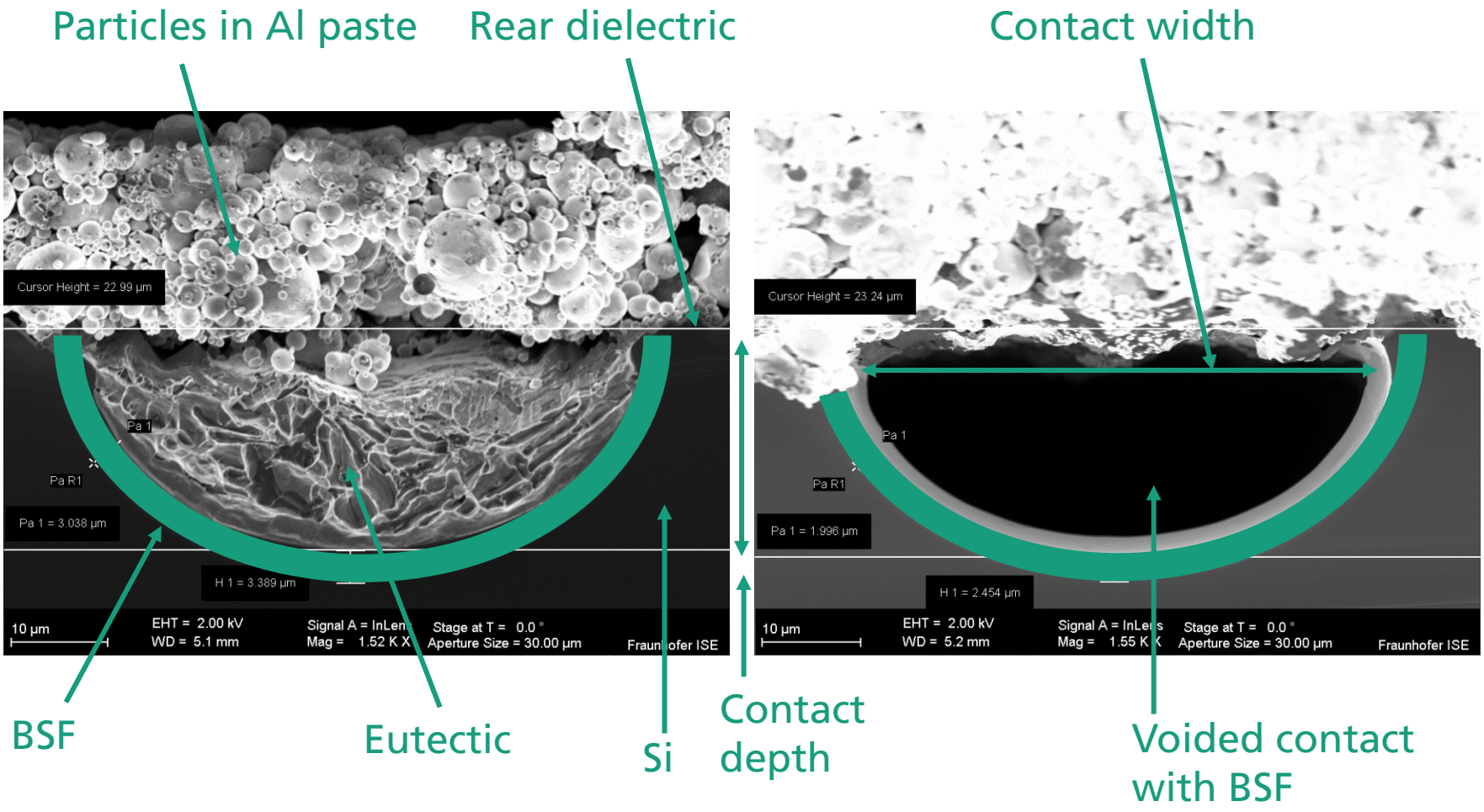
Motivation

Characterization of local rear contacts



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Motivation
State of the art

Parameters known to affect local contact and void formation

- Width of laser opening [1, 5]
- Particles size in Al paste [2]
- Si content in Al paste [3, 4, 5]
- Al paste thickness and confined printing [6, 7, 8]
- Firing profile
  - Temp. plateaus before peak zone [9]
  - Cooling rate [2]
  - Heating rate [2]

References

[1] E. Urrejola, Met. Workshop 2011.

[2] K. Dressler, IEEE JPV 2016.

[3] M. Rauer, IEEE EDL 2011.

[4] Y. Chen, IEEE PVSC 2014.

[5] T. Lauermann, PIP 2015.

[6] C. Kranz, IEEE JPV 2015.

[7] T. Dullweber, PIP 2015.

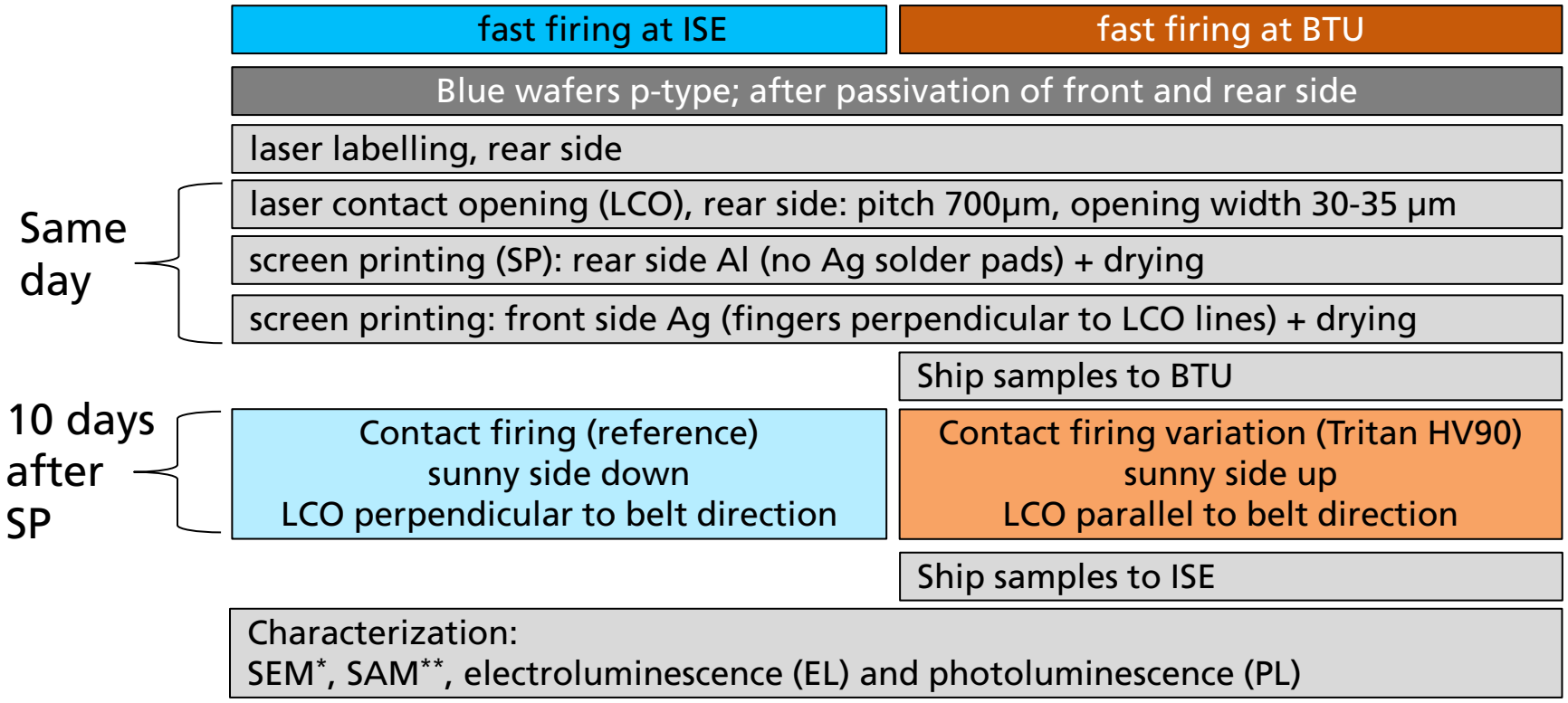
[8] D. Lin, IEEE PVSC 2014.

[9] D. Chen, EU-PVSEC 2013.

Motivation
Purpose of the work

- Comparison of different firing profiles and
- Comparison of different characterization methods for local contacts

Experiment layout



*SEM: Scanning Electron Microscopy

**SAM: Scanning Acoustic Microscopy

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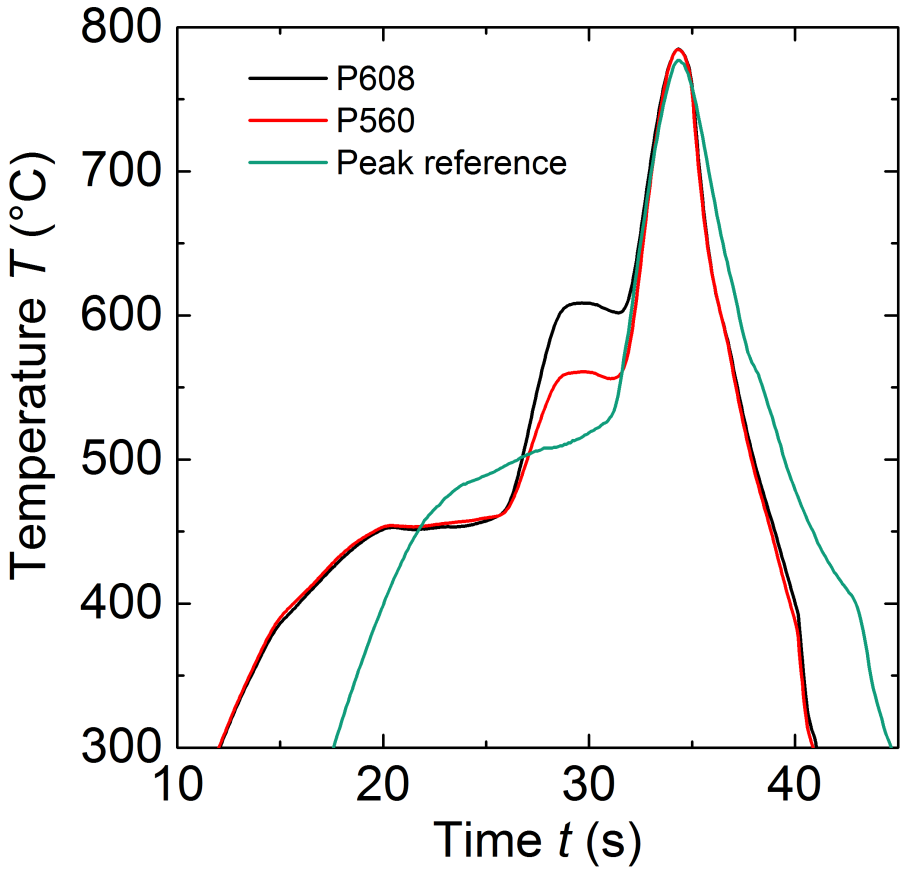
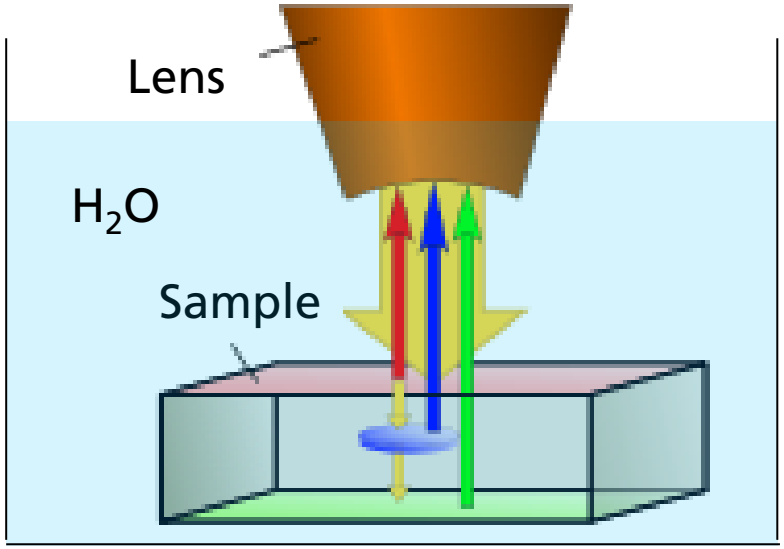
Firing Profiles
Pre-plateau

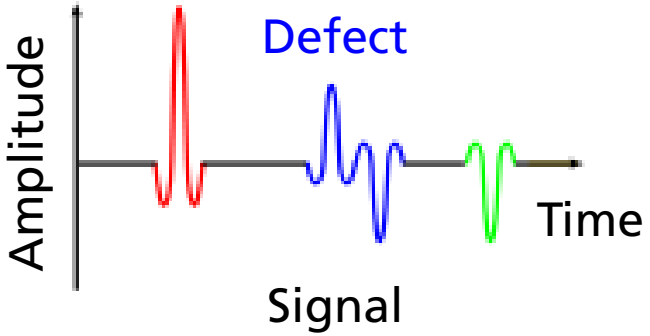
- Idea: lowering the Si concentration gradient at the Al/Si interface by saturation of Al with Si
- Comparison of three firing profiles
  - BTU: Plateau of 608°C for 3s before peak („P608“)
  - BTU: Plateau of 560°C for 3s before peak („P560“)
  - ISE: Peak reference



Pre-Plateau
Scanning acoustic microscopy (SAM)

- Scanning acoustic microscopy for void detection at locar rear contacts
- Sound reflectance at voids
- Time consuming measurements in water (10-30 min per image)

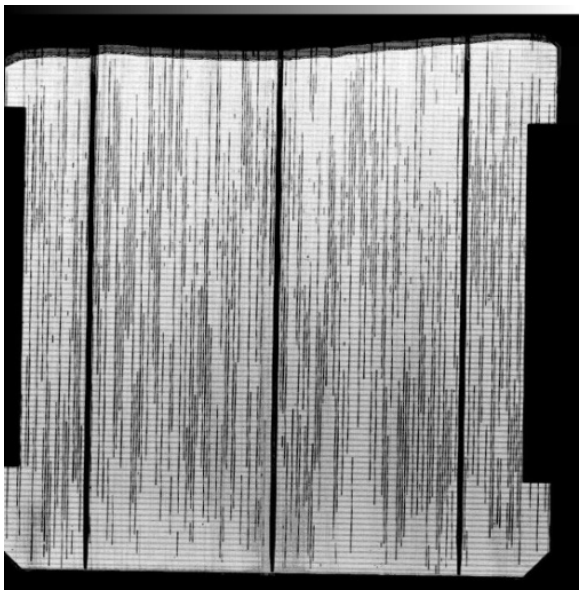




Source: after wikipedia.de

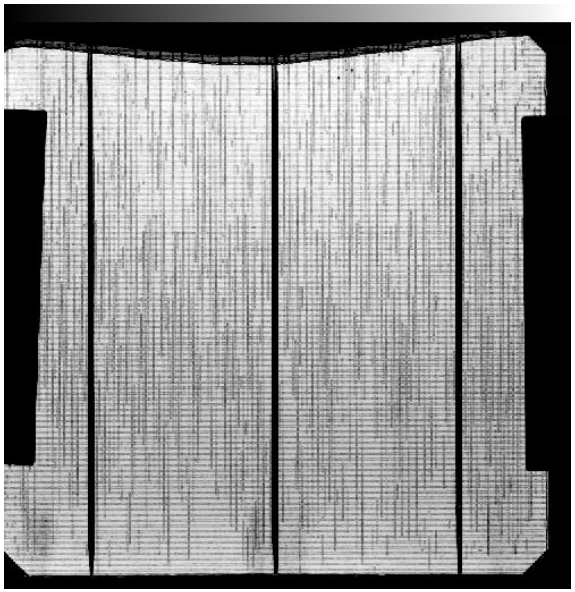
Pre-Plateau
Scanning acoustic microscopy (SAM)

Peak reference



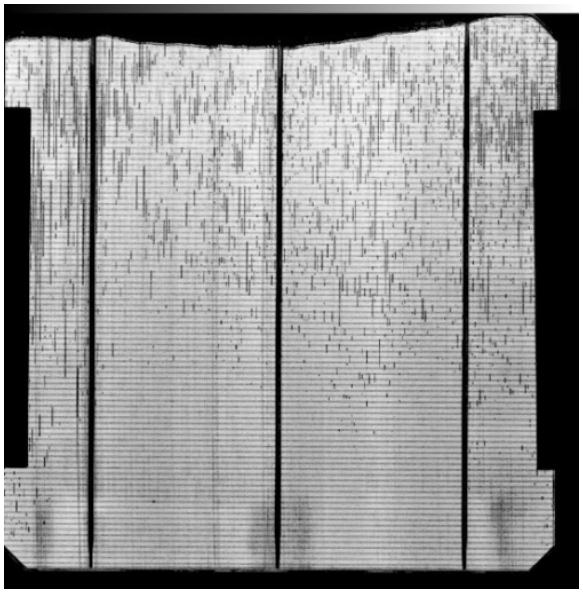
- Lots of voids
- Voids of several cm

P560



- Void density and length similar to peak profile

P608



- Lowest void density
- Interrupted voids
- Voids only on last half during firing (*T* effect) [1]

➔ SAM ideal tool for void analysis, but not inline capable

[1] R. Horbelt, EU-PVSEC 2014.

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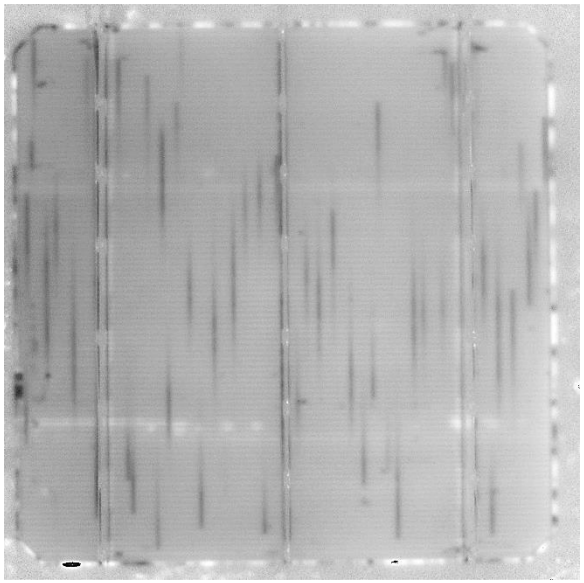
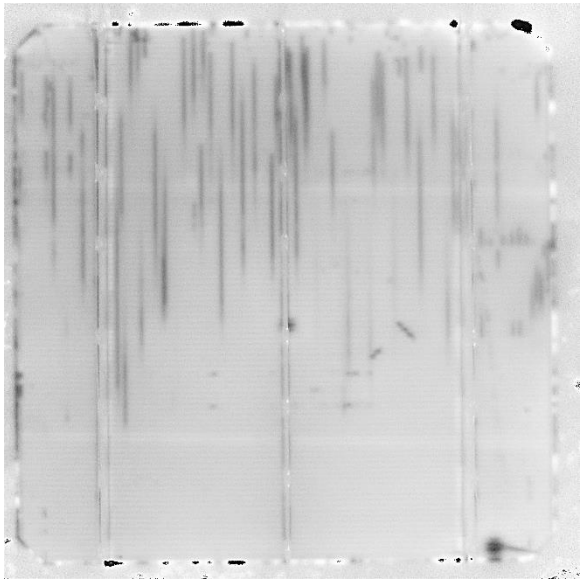
Pre-Plateau
Photoluminescence (PL)

Peak reference



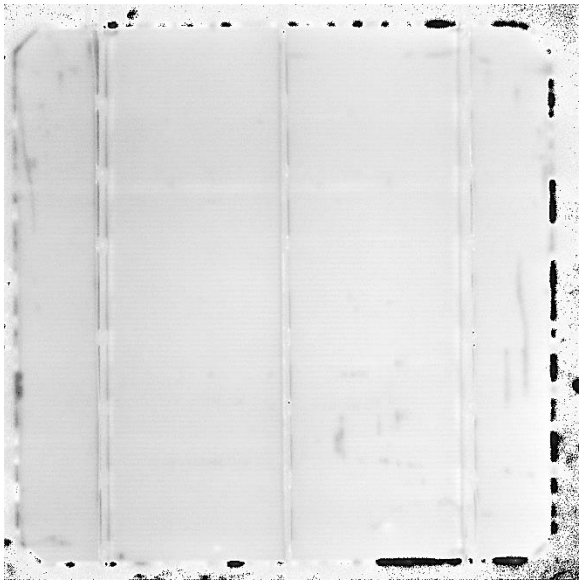
- Recombination only locally increased

P560



- High recombination only in upper half

P608



- Homogeneous appearance in PL

➔Not all voids are detrimental
➔Some voids are recombination active
➔Measurement time of ~1s

[1] R. Horbelt, Energy Procedia 84, 2015.

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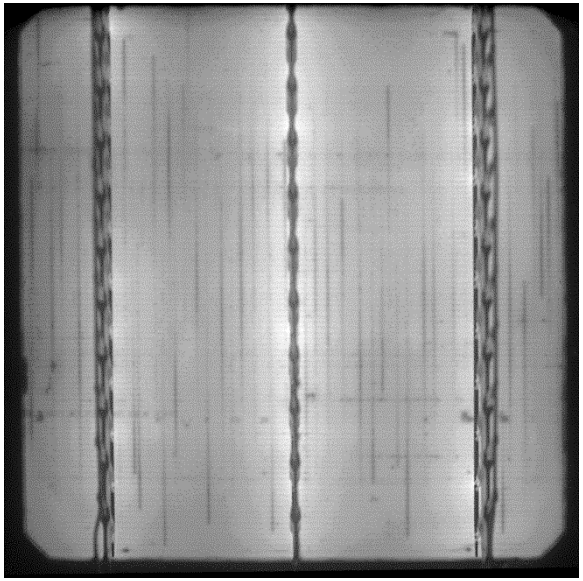
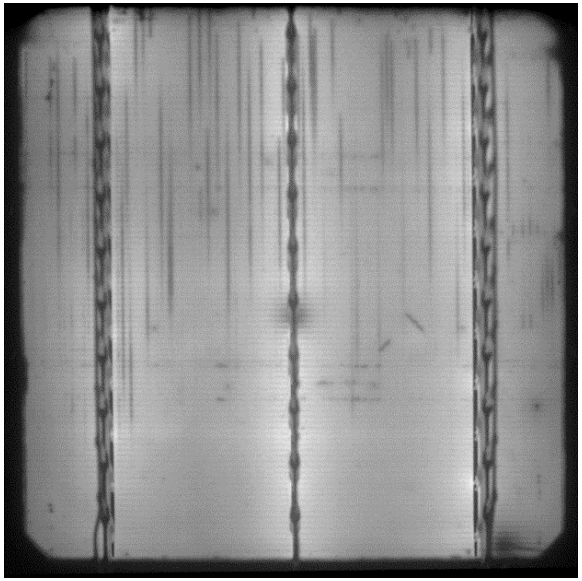
Pre-Plateau
Electroluminescence (EL)

Peak reference



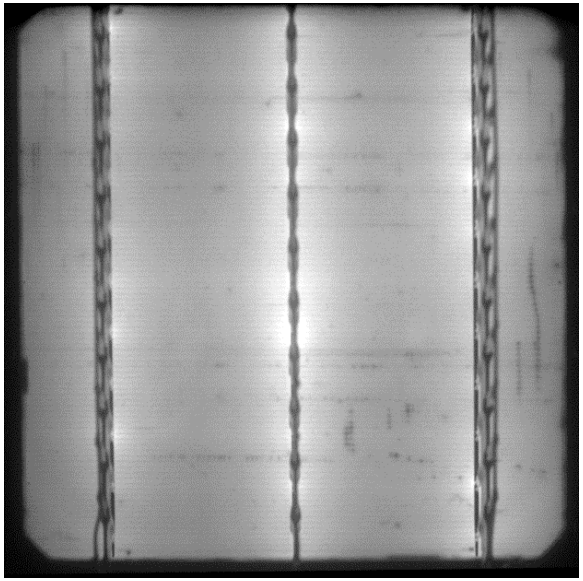
- Contact resistance only locally increased

P560



- High contact resistance only in upper half

P608



- Homogeneous appearance in EL

➔Voids might lead to locally increased series resistance values [1], or again effect of increased recombination

➔Measurement time of ~1s

[1] R. Horbelt, Energy Procedia 84, 2015.

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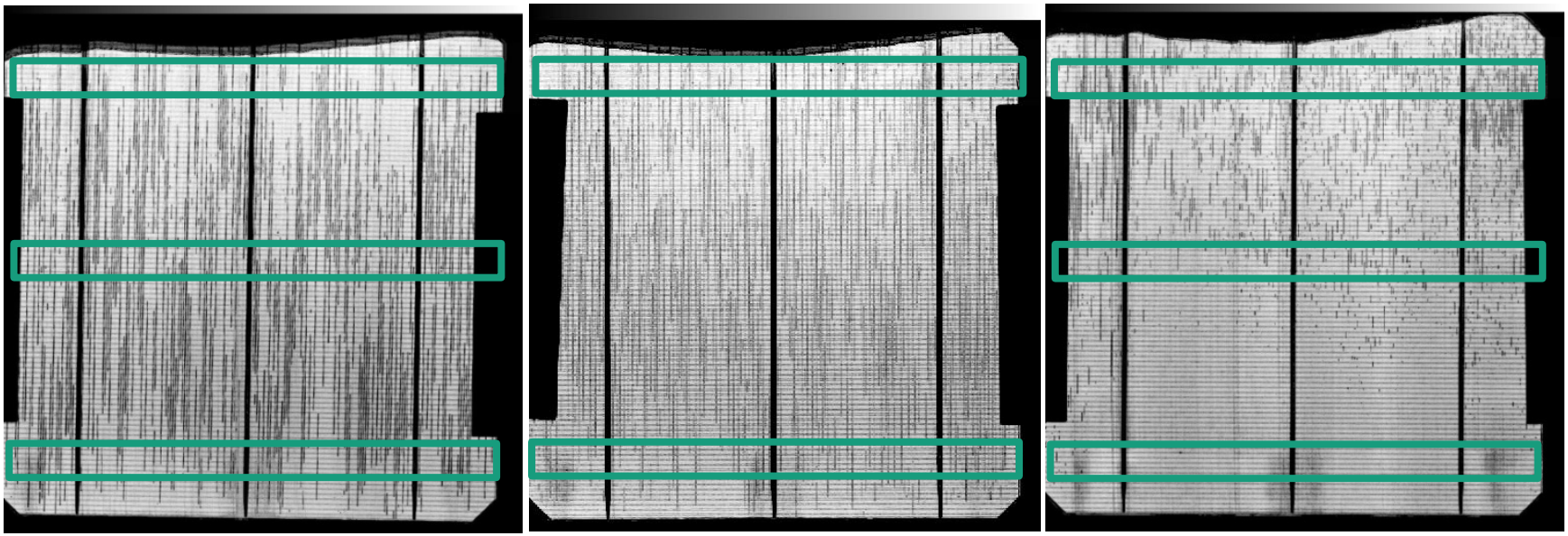
Pre-Plateau
Cuts for SEM characterization

Peak reference P560 P608

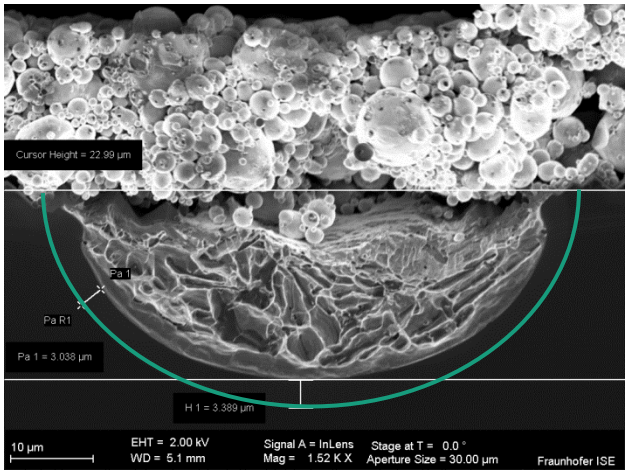


- Cross sections at three or two cuts from each wafer analyzed by SEM

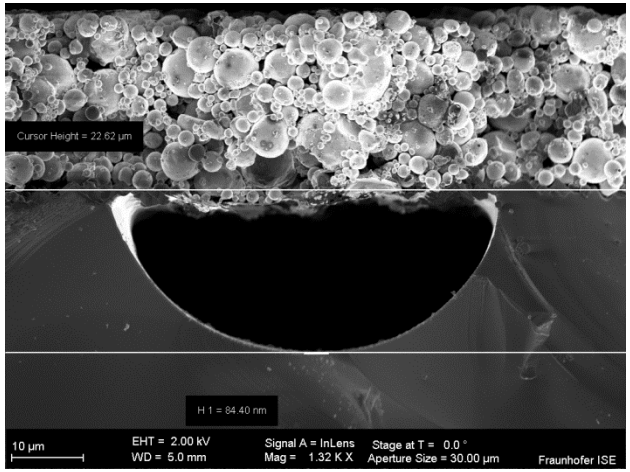
Pre-Plateau
Scanning electron microscopy (SEM)

- 3 types of contacts

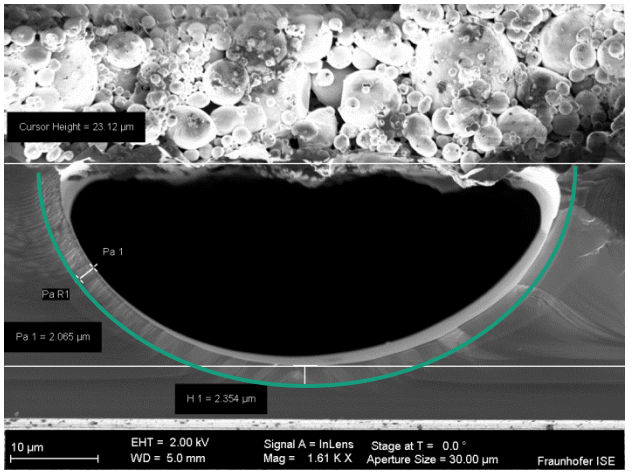
Filled contact, with BSF



Void, without BSF



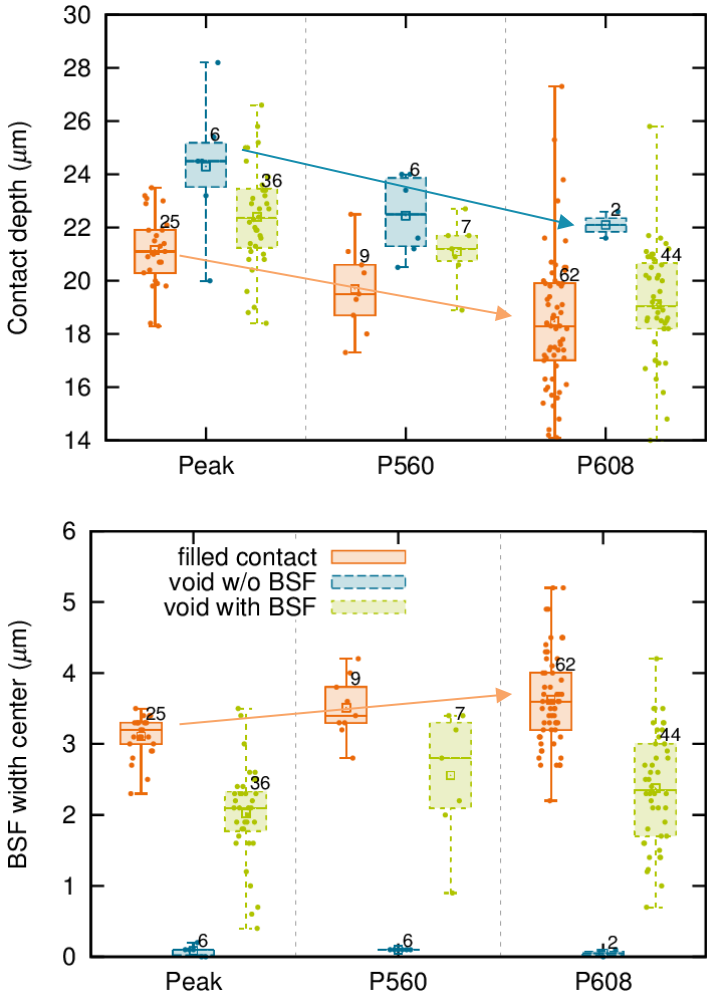
Void, with BSF



Pre-Plateau
SEM contact analysis

- Contact depth
  - Voided contacts are deeper, especially without BSF
  - Decreases for higher plateau temperatures
- BSF width
  - Deeper for filled contacts [1]
  - Increases for higher plateau temperatures

➔ Pre-plateau at 608°C yields lowest contact depth and thickest BSF



[1] R. Horbelt, EU-PVSEC 2014.

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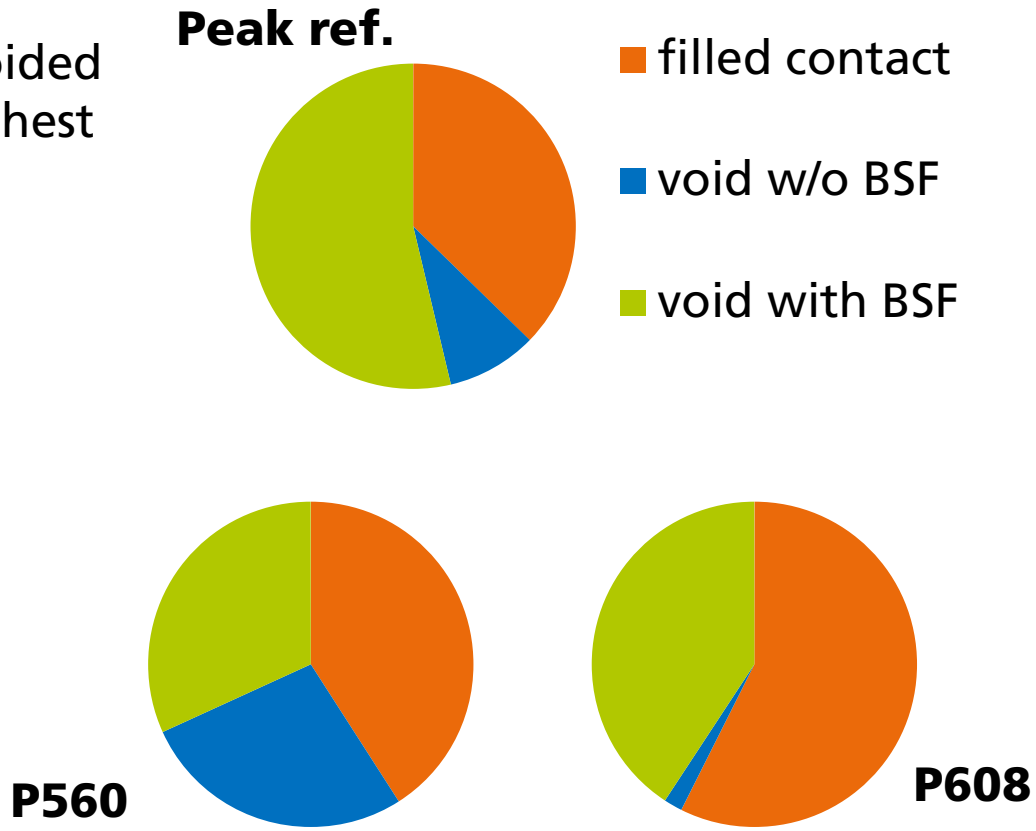
Pre-Plateau
SEM contact analysis

- Distribution of contacts types
- P608 yields lowest ratio of voided contacts without BSF and highest ratio of filled contacts

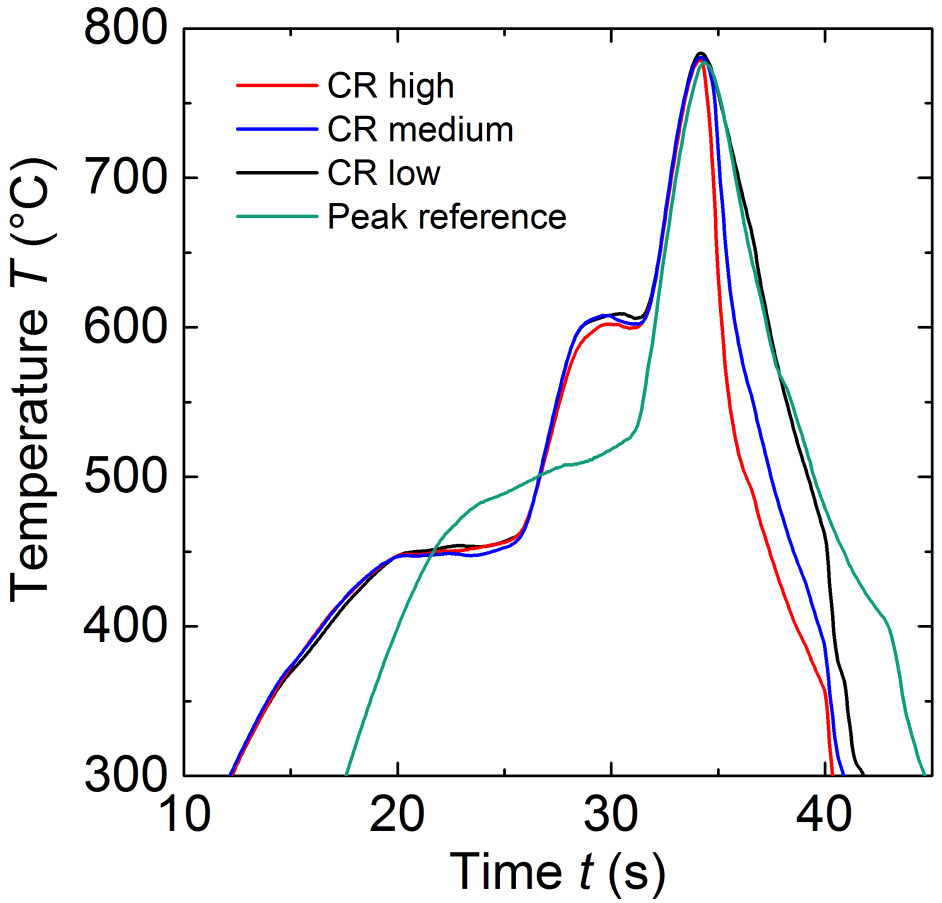


Summary
Pre-plateau

- Voids directly confirmed by SAM
- Correlation with SEM, PL and EL images realized
- Implementation of a 600°C plateau considerably reduces void formation in PERC cells and yields interrupted voids
- Recombination at voided contacts effectively suppressed by thick BSF

Firing Profiles
Cooling rate variation

- Idea: allow Si to diffuse back into local contacts
- P608 as starting process
- Cooling rate from T_{max} until 577°C
  - BTU: High -173 K/s
  - BTU: Medium -106 K/s (P608)
  - BTU: Low -58 K/s
  - ISE: Peak -61 K/s

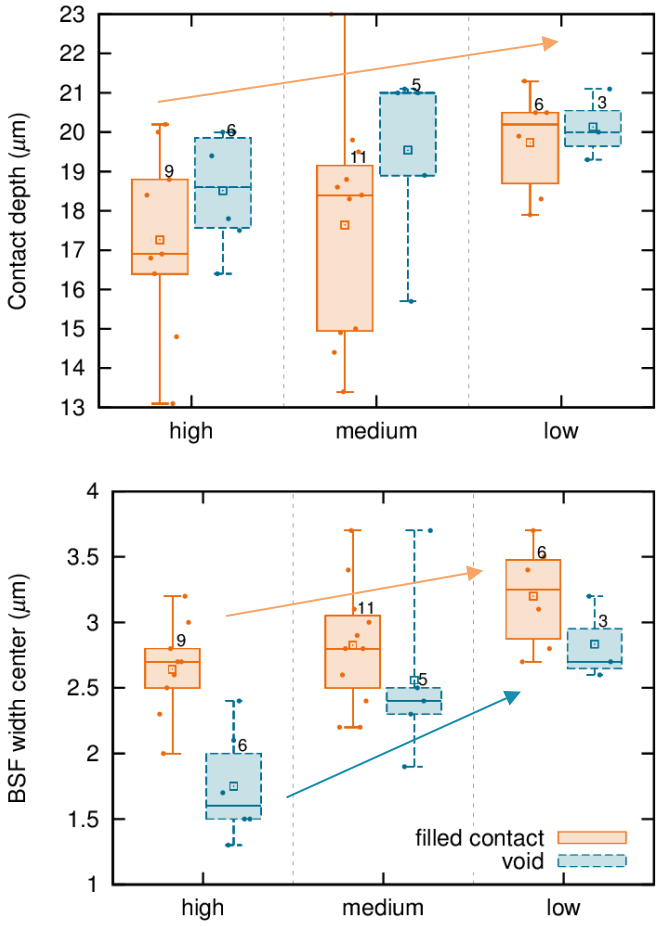


Impact of Cooling Rate
SEM contact analysis

- Measurements on top region of wafer
- Lower cooling rate
  - Increases contact depth
  - Increases width of BSF, especially for voided contacts

➔ Low cooling rates (-60K/s) beneficial for achieving thick BSFs

➔ Applied cooling rate still relevant for industrial manufacturing



Impact of Cooling Rate
SEM contact analysis

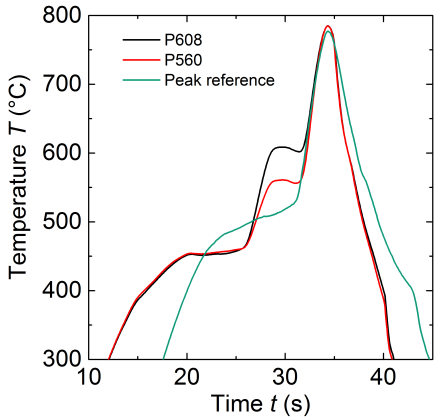
- Counting of voids and filled contacts at SEM cross section cuts

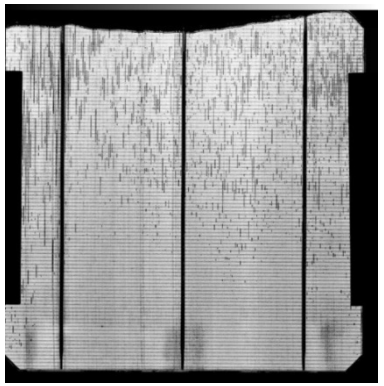
Plateau	Cooling rate	Contacts investigated	Ratio of voided contacs
600°C	High	66	24%
600°C	Medium	76	20%
600°C	Low	141	15%
Peak	Low	439	41%

- ➔ Low cooling rates clearly reduce the number of voids
- ➔ 600°C plateau before firing strongly reduces void appearance compared to ISE peak reference process
- ➔ Impact of additional plateau is stronger than cooling rate

Summary

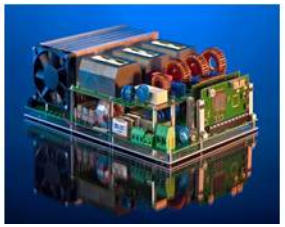
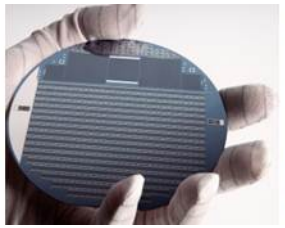
- Different fast firing profiles for PERC solar cell fabrication have been developed
- Local contacts investigated by a combination of SEM, SAM, EL, PL
- Void reduction shown by both pre-plateau above 600°C and low cooling rates
- Electroluminescence identified as fast method for evaluating quality of local rear contacts





Thank you for your attention!




… my colleagues at Fraunhofer ISE

… our industry partner BTU and German ministry for funding

This work was supported by the German Federal Ministry for Economic Affairs and Energy within the research project “CUT-A” under contract number 0325823

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Gefördert durch:

Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages