PERC MEETS PARALLEL DISPENSING

Tuning the Front Side of Silicon Solar Cells by Contact-less Printing

M. Pospischil, S. Tepner,
M. Kuchler, M. Klawitter,
I. Lacmago, L. Ney,
M. Breitenbücher, F. Clement

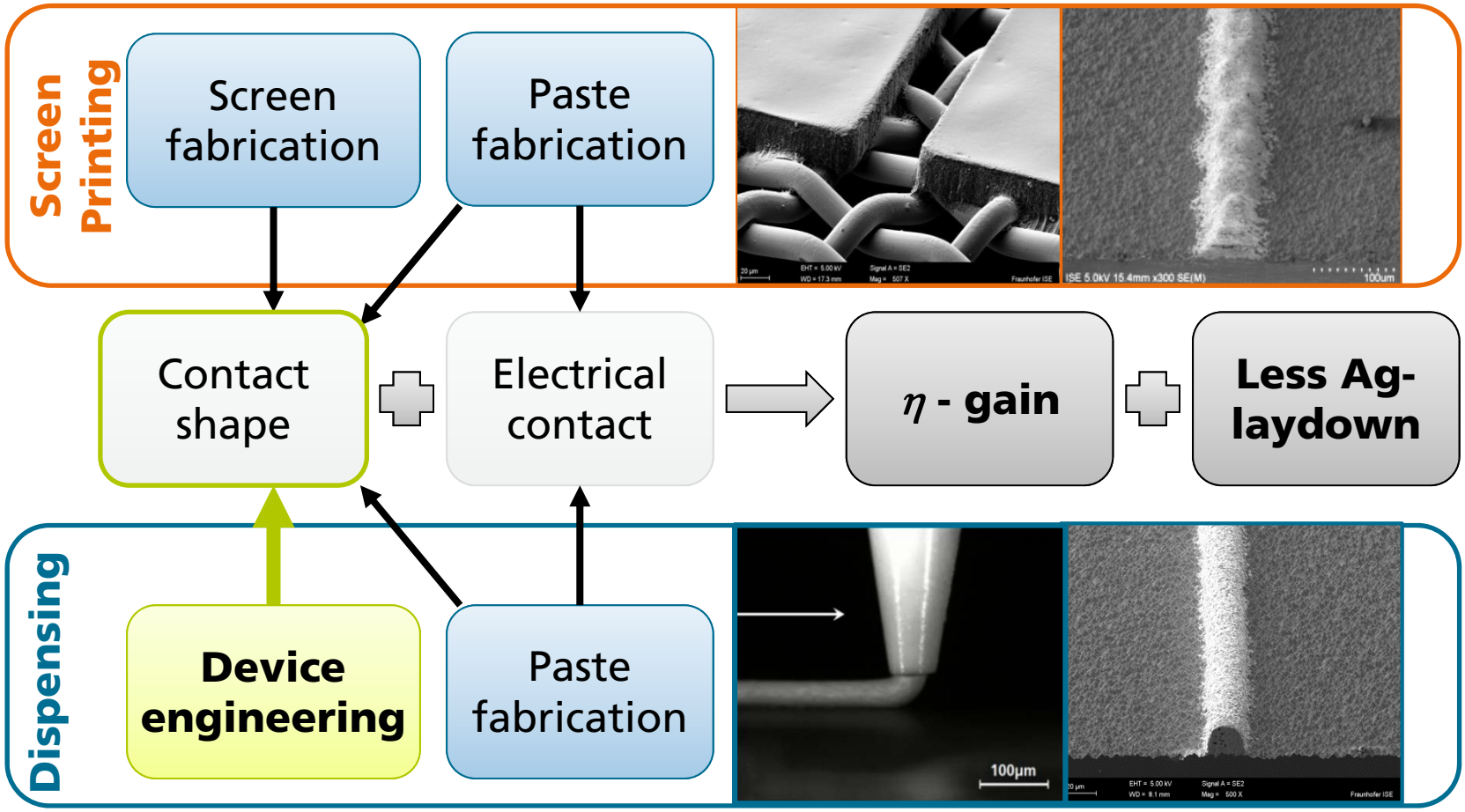
7th Metallization Workshop
Constance, Oct 23rd 2017

www.ise.fraunhofer.de

Fraunhofer
ISE

PV Front Side Metallization

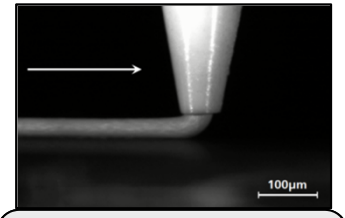
Looking for Innovative Production Tools



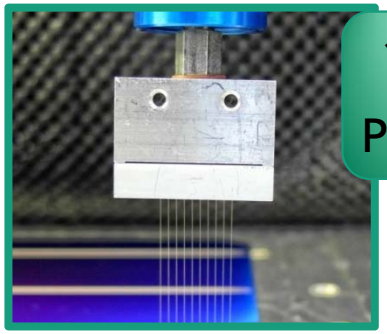
Fraunhofer ISE

Dispensing at Fraunhofer ISE

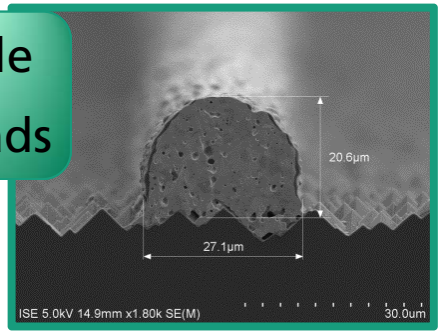
Development of Multi Nozzle Print Heads



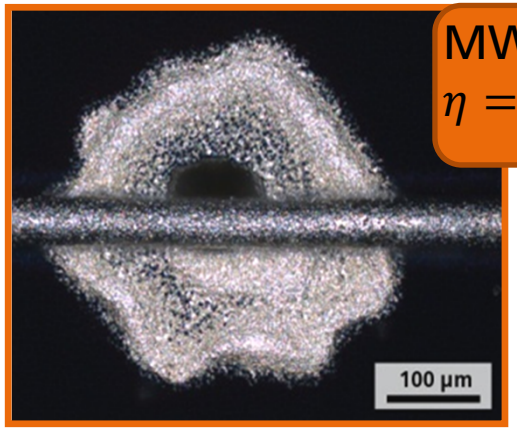
Single Nozzle Dispenser



10 Nozzle Print Heads

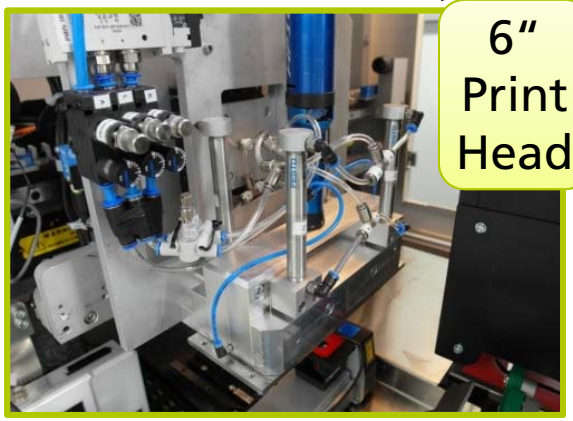


2010 2011 2012 2013 2014 2015 2016



MWT-PERC: $\eta = 20.6\%$

ASYS Dispense Platform



6" Print Head

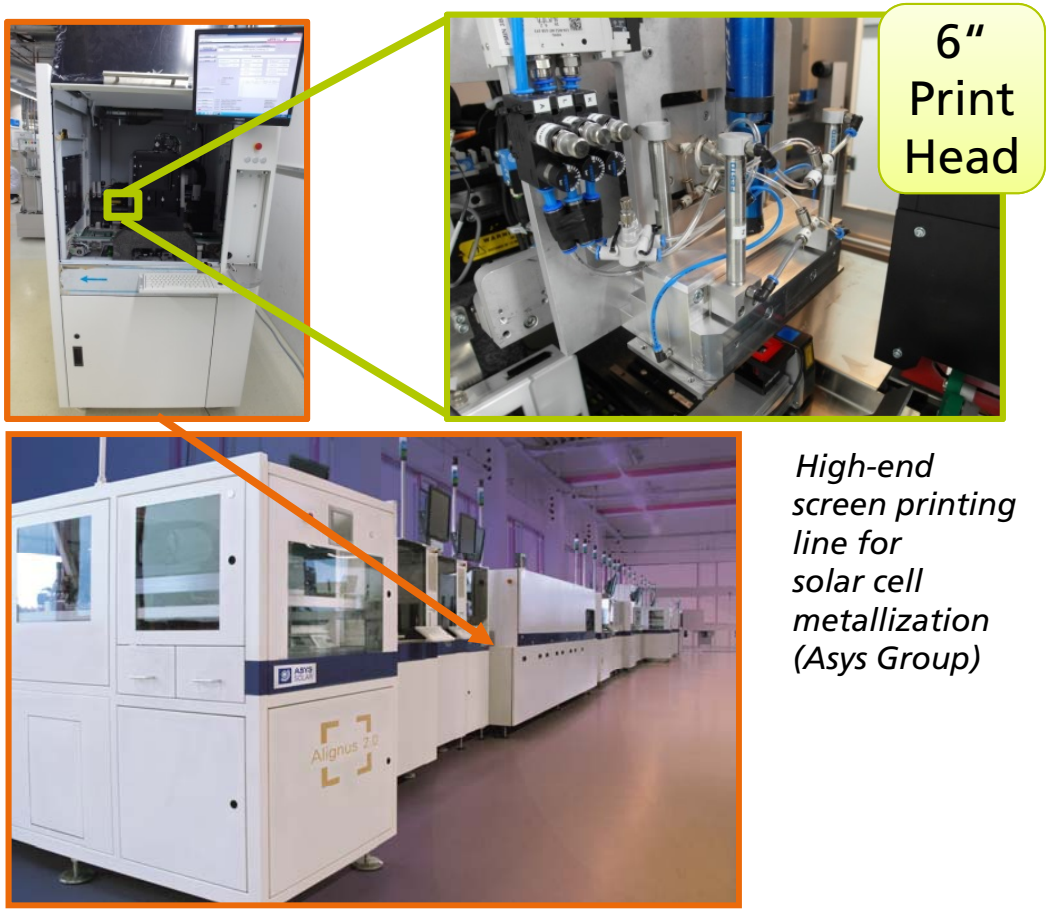
J. Specht *et al.*, 25th EU-PVSEC, 2010
E. Lohmüller *et al.*, IEEE EDL **32**, 1719 (2011).
M. Pospischil *et al.*, Energy Proc. **43**, 111 (2013).
M. Pospischil *et al.*, Energy Procedia **98**, 61 (2016).

Fraunhofer ISE

Goal: Integration in PV Metallization Lines
Dispenser as Drop-In-Replacement

From Q1/18 in PV-TEC again!

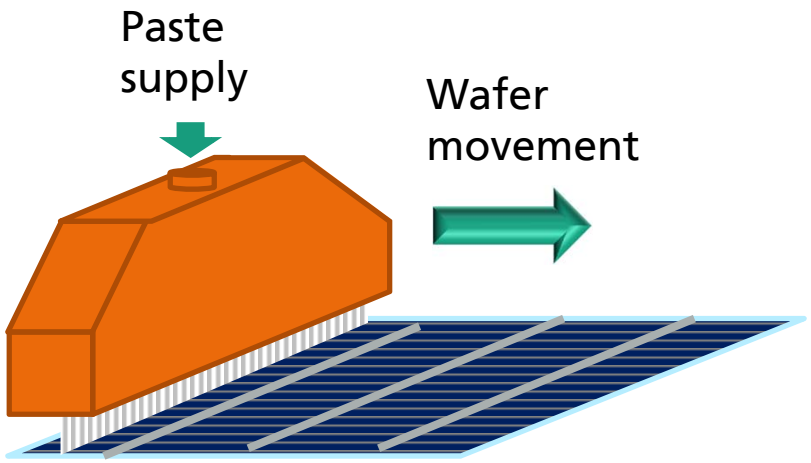
- Screen printing with integrated dispenser
- Dual-print (floating busbar)
- No drying in between consequent print steps!
- High printing speed $v = 800\ mm/s$



High-end screen printing line for solar cell metallization (Asys Group)

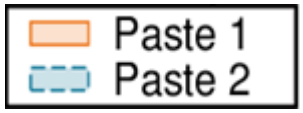
PARALLEL DISPENSING - OUTLINE

- Background & Motivation
- Continuous Operation
  - IV - Results on PERC
  - Paste consumption
  - Contact geometries
- Intermittent Operation
  - Challenges
  - Current Process: Semi Contact
  - Outlook: On the Fly
- Summary & Outlook

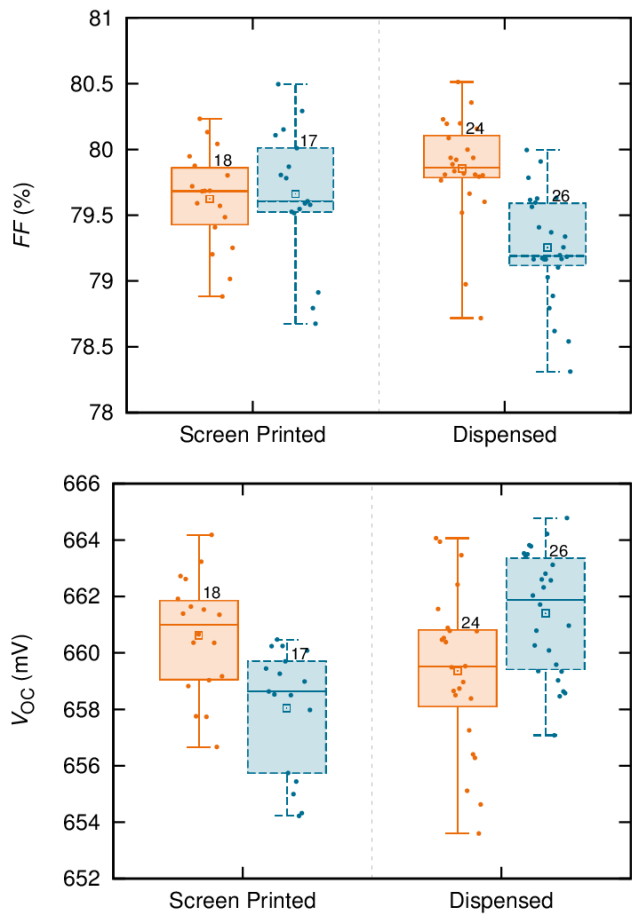


Schematic of the dispensing process using a full wafer size parallel printhead.

Latest PERC-Sampling in PV-Tec
Design of Experiment

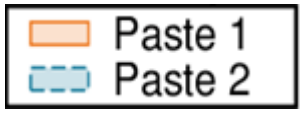


- 156 x 156 mm² Cz p-type Si
- Preprocessed until printed Al-backsurfaces
- Screen printed references
  - Screen opening w_s = 40µm
- Dispensed groups
  - Nozzle diameter D = 35µm
- Number of contact fingers
  - N_f = 100 (all groups)
- **Ag-Paste variation**
  - Two commercially available samples of different manufacturers

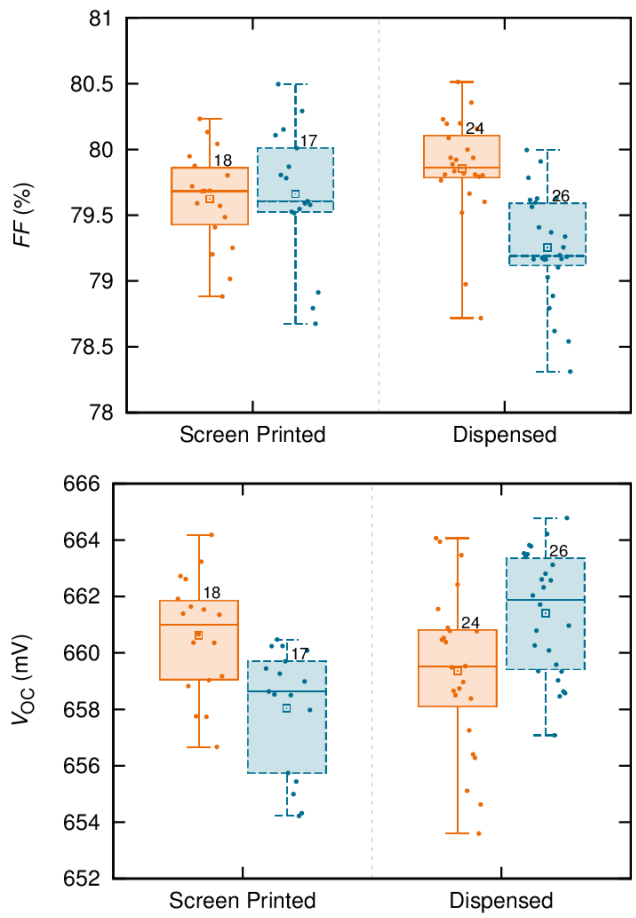


Fraunhofer ISE

Latest PERC-Sampling in PV-Tec
FF and V_{oc}



- Fill factor *FF* and open circuit voltage V_{oc} on similar level at all groups



Fraunhofer ISE

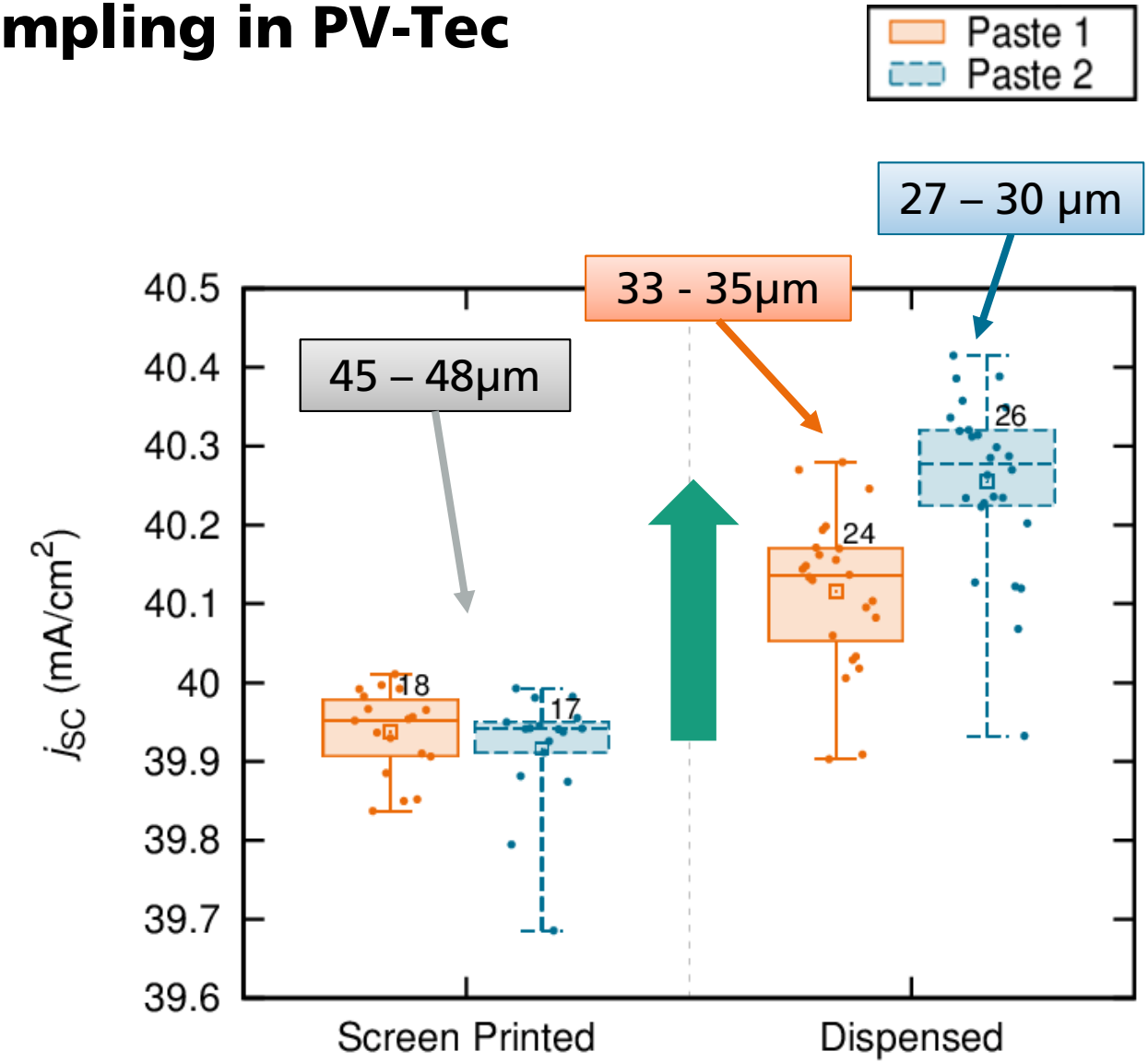
Latest PERC-Sampling in PV-Tec

J_{sc} gain

- Significant gain

  $\Delta j_{sc}/j_{sc}$ ~ 1%

→ **Substantially reduced shading**

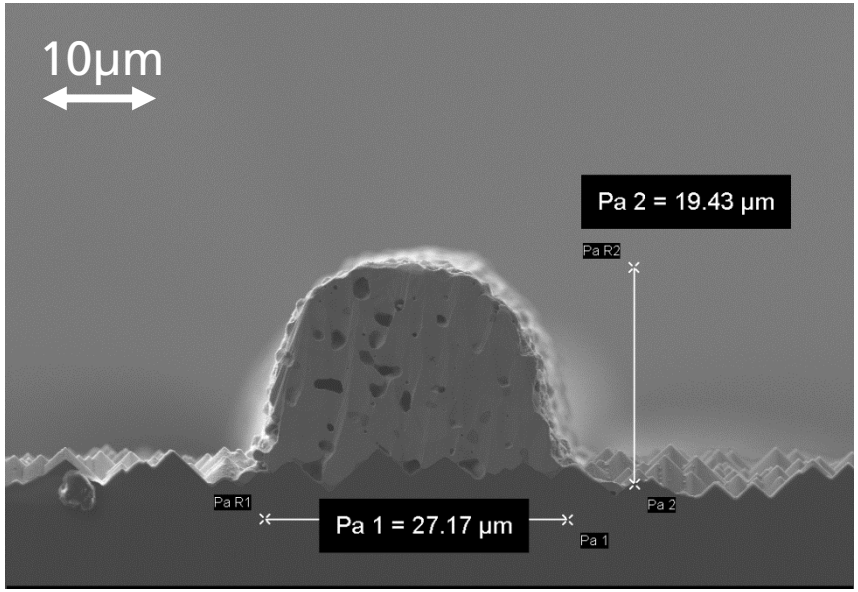


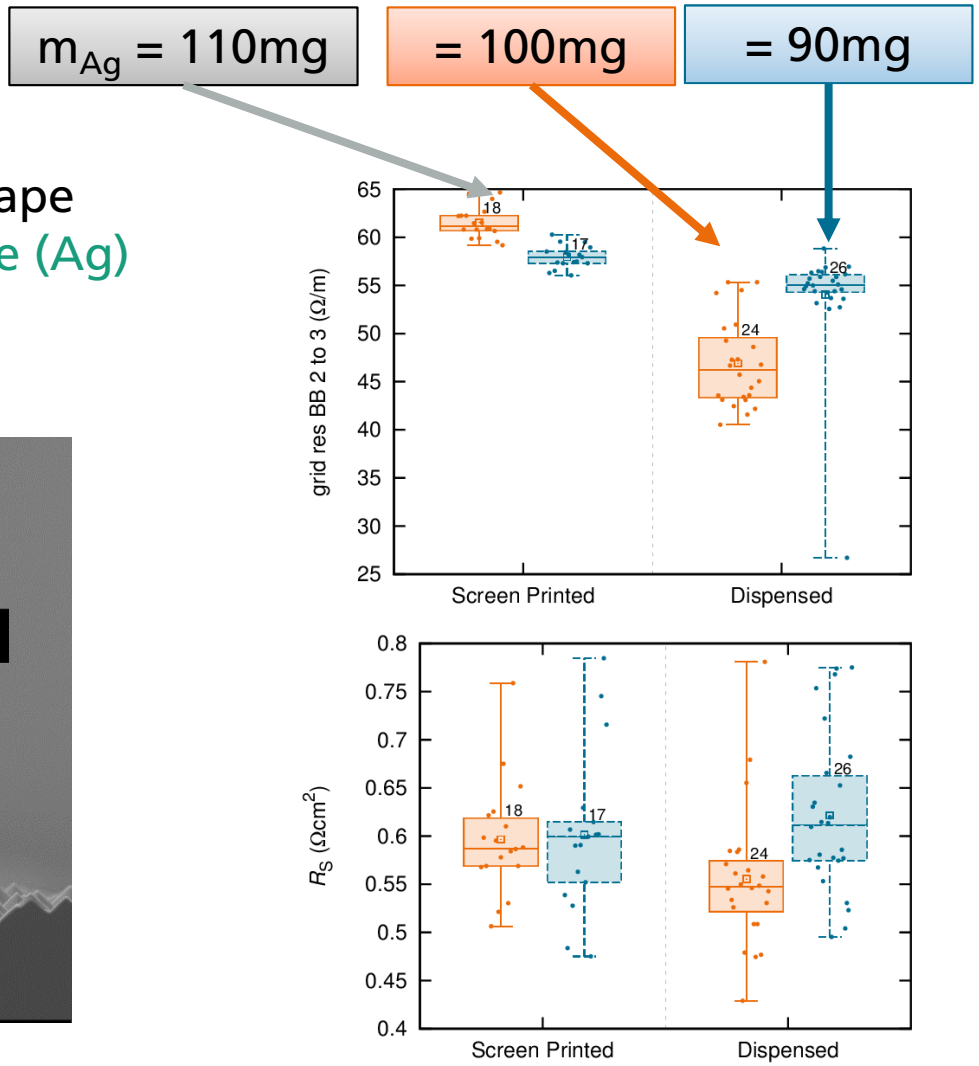
Fraunhofer ISE

Latest PERC-Sampling in PV-Tec

R_s and GridRes Analysis

- More homogeneous contact shape
  → more efficient material usage (Ag)
- Stable processing @ w_f = 27µm





Fraunhofer ISE

Latest PERC-Sampling in PV-Tec
Gain in Efficiency

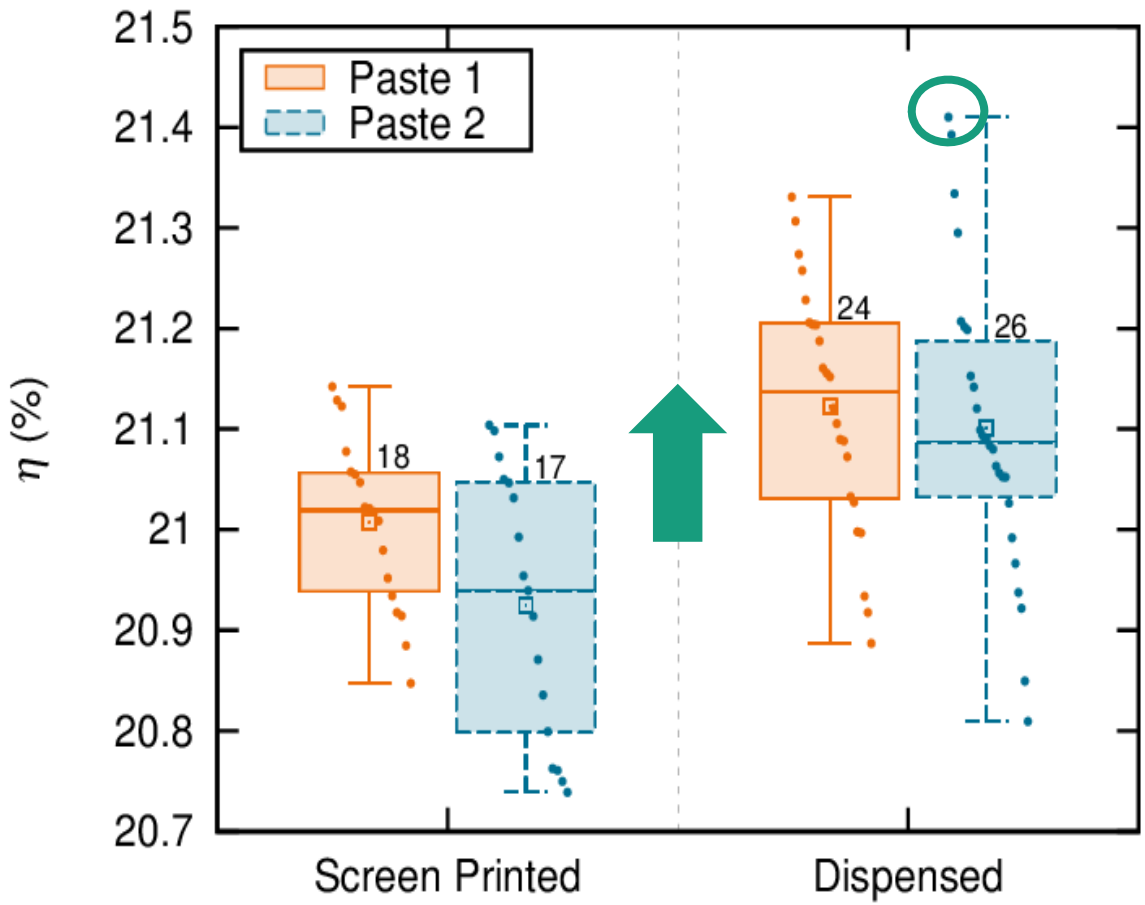
- Less shading

  $\Delta j_{sc}/j_{sc}$ ~ 1%

- *FF* and V_{oc} on similar level
- $\Delta m_{Ag}/m_{Ag}$ = -19% at similar R_s

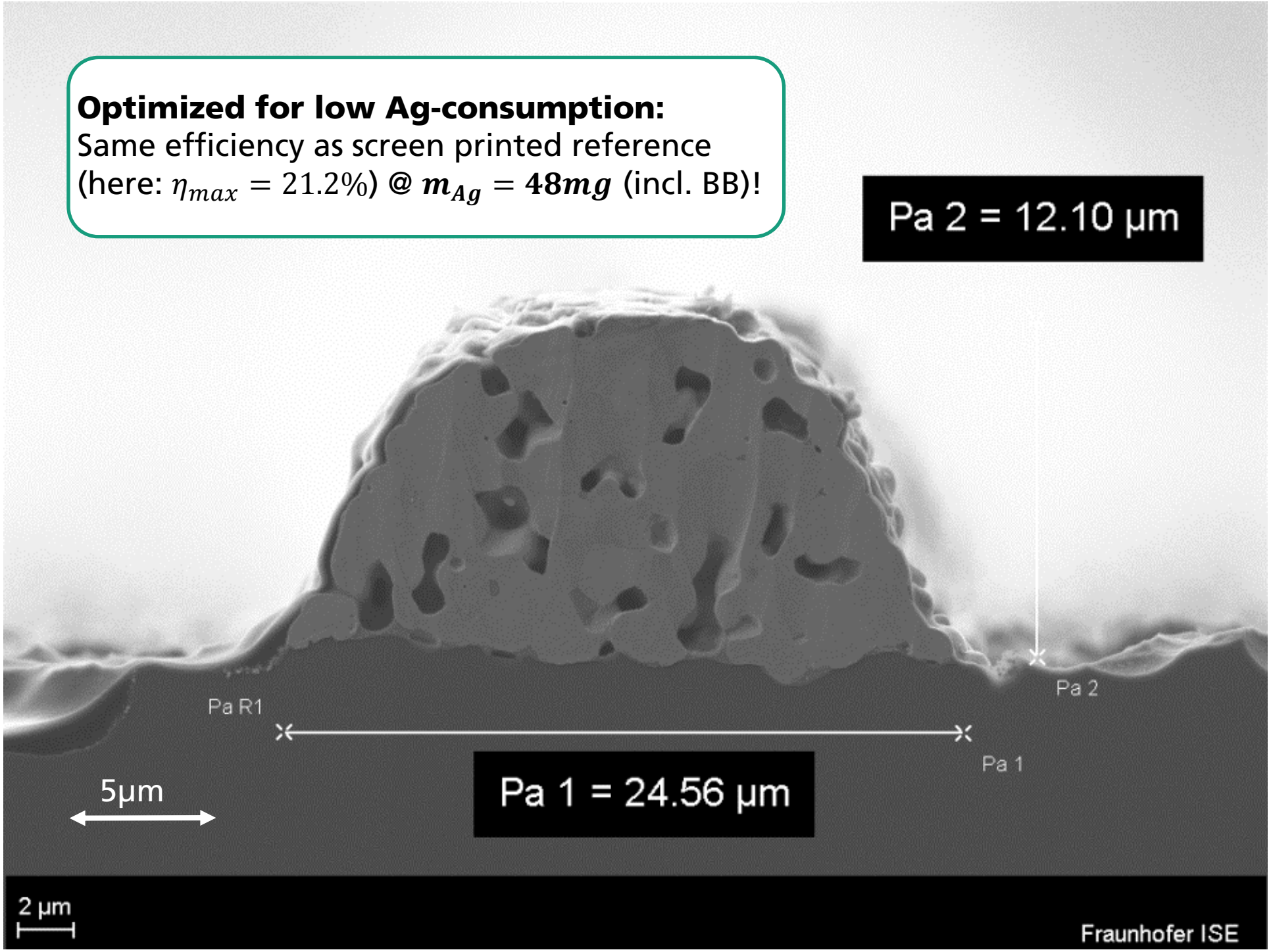
→ $\Delta\eta/\eta$ ~ 1%

→ **η_{max} = 21.4%**



Fraunhofer ISE

Optimized for low Ag-consumption:
Same efficiency as screen printed reference (here: $\eta_{max} = 21.2\%$) @ $\boldsymbol{m_{Ag} = 48mg}$ (incl. BB)!



Improving Contact Geometries

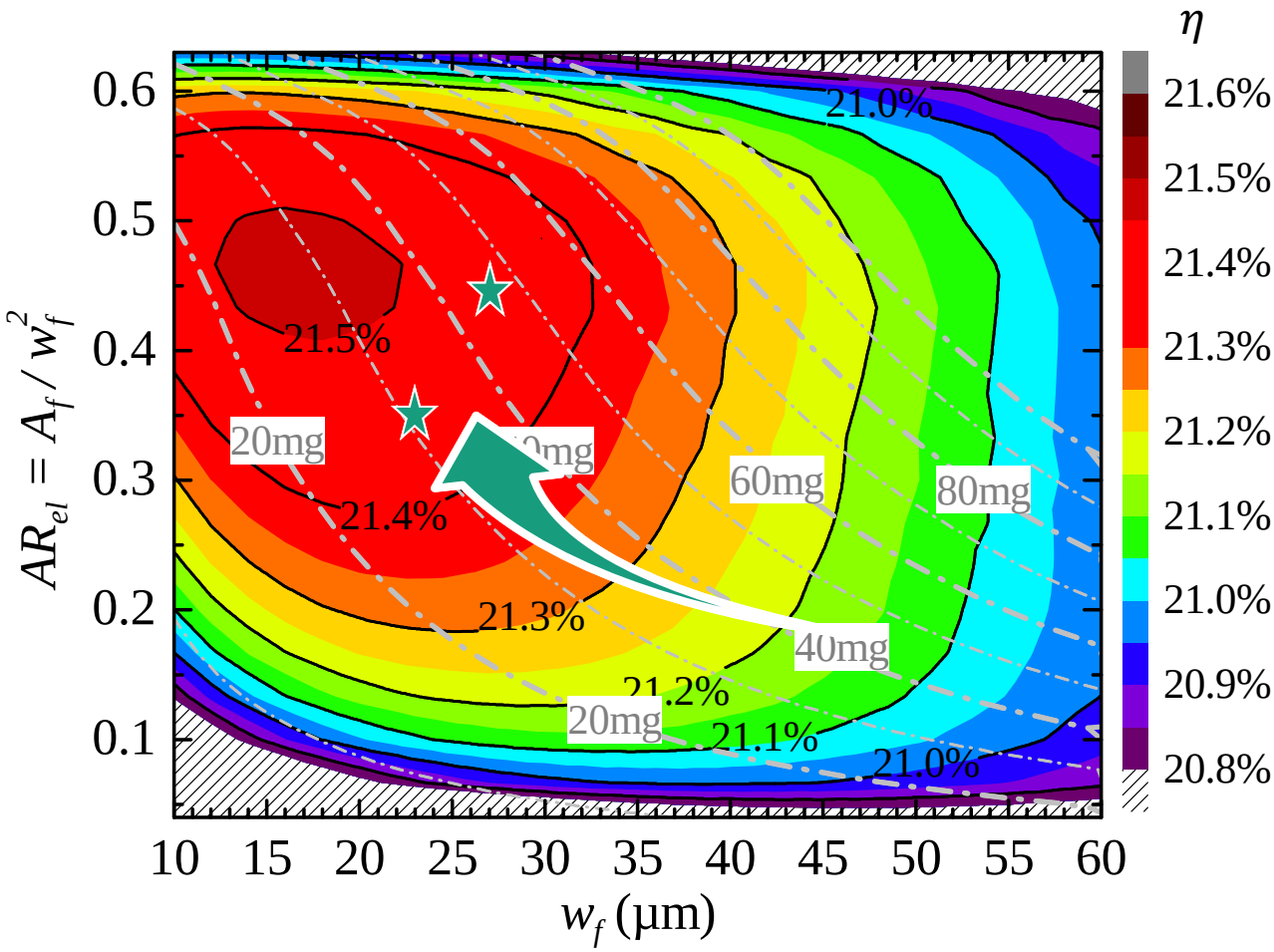
Gridmaster: Where is the optimum for 5BB PERC?

Goal

- Ideal contact shape for specific paste

Future improvements

- Enable further efficiency increase of $\Delta\eta \sim 0.2\%$
- Reduction of wet paste consumption to $m_f < 30$mg

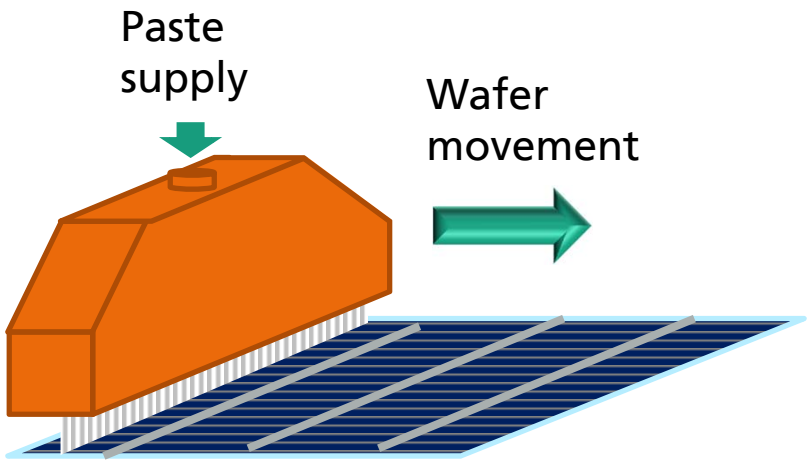


* T. Fellmeth et al., IEEE JPV **4**, 504 (2014).
M. Pospischil *et al.*, Energy Procedia **55, 693 (2014).

Fraunhofer ISE

PARALLEL DISPENSING - OUTLINE

- Background & Motivation
- Continuous Operation
  - IV - Results on PERC
  - Paste consumption
  - Contact geometries
- **Intermittent Operation**
  - **Challenges**
  - **Current Process: Semi Contact**
  - **Outlook: On the Fly**
- Summary & Outlook



Schematic of the dispensing process using a full wafer size parallel printhead.

Challenges of Intermittent Dispensing
Acting Forces at Nozzle Exit

Crucial Parameters

- Yield stress τ_y
- Surface tension σ

$$Re_y = \frac{\rho \cdot \bar{u}^2}{\tau_y}$$

$$Ca_y = \frac{\tau_y \cdot D}{2\sigma}$$

$$We = \frac{\rho \cdot \bar{u}^2 \cdot D}{2\sigma}$$

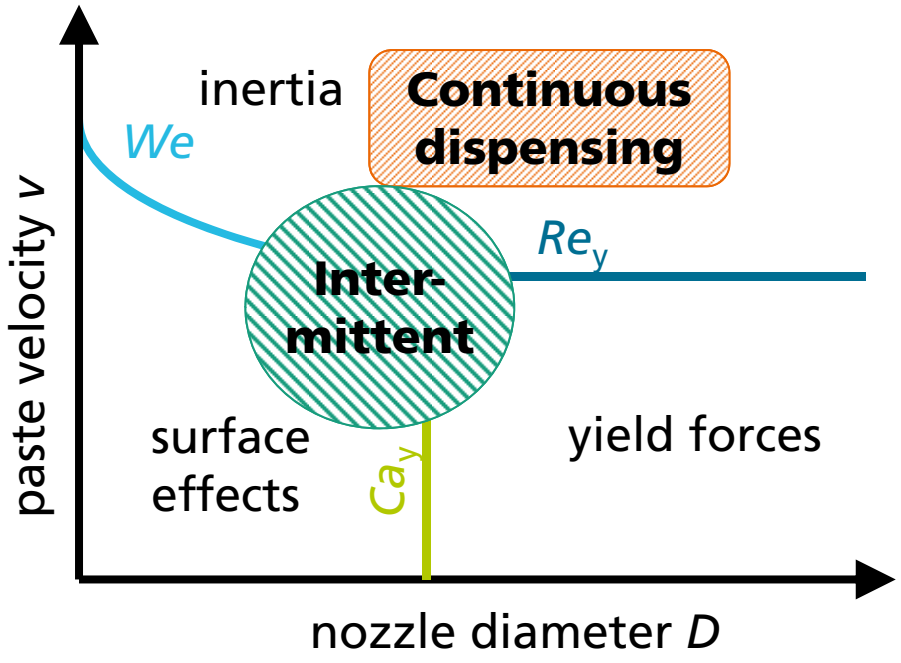
Continuous Operation

- inertia driven flow

Intermittent Operation

- Paste velocity drops dynamicly

→ Surface effects dominate @ small nozzle diameters *D*

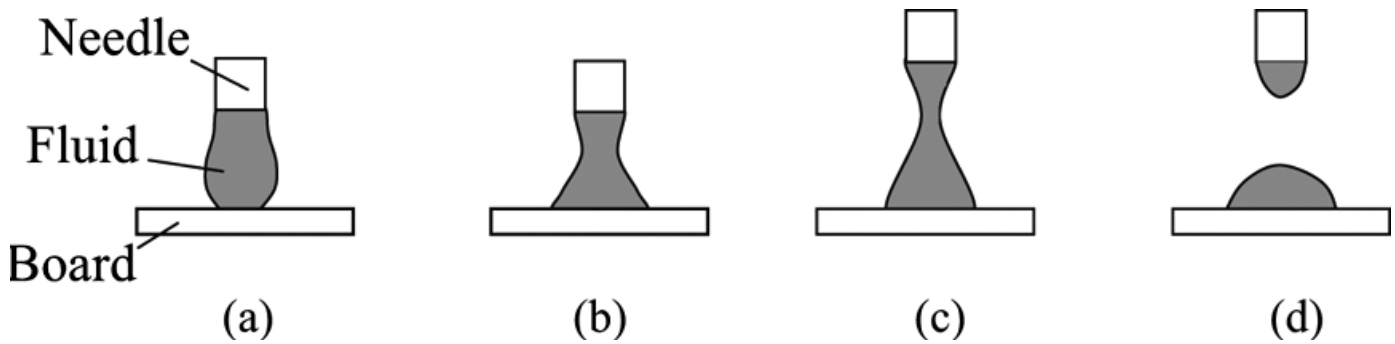


M. Pospischil, Thesis, University of Freiburg, 2016

Fraunhofer ISE

Intermittent Dispensing
First Approach: Semi-contact

- Line-start: Fluid-**meniscus** is brought into contact with substrate
- Line dispensing: As usual, but with **velocity** and **acceleration** profile
- Line-End: Triggered break-off, by controlled movement (*y* and/or *z*)



Source: Chen et al., Electronics Packaging Manufacturing, IEEE Transactions on **32**, 133 (2009).

→ Prevents wetting issues at line start

→ Requires perfectly parallel aligned nozzles (dispense gap!)

Intermittent Dispensing
Current Status

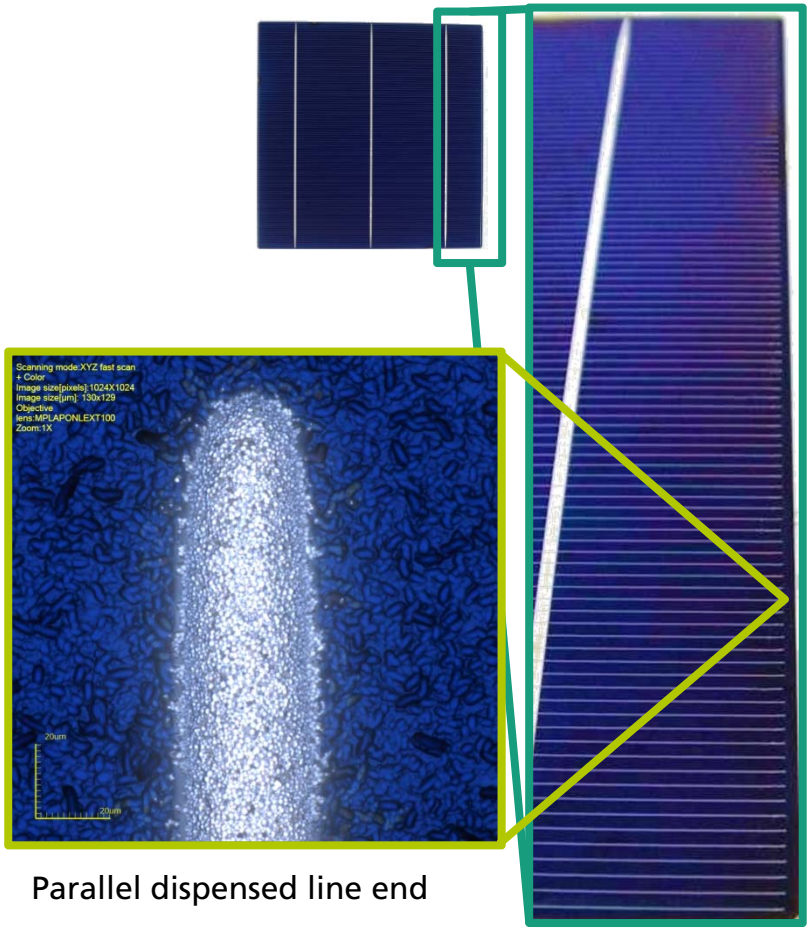
Semi-contact

- First process established on 10 x parallel print head
- Precisely fabricated nozzle plates ensure homogeneous dispense gap
- High process stability (no wetting!)

→ First cell batches planned for end 2017

Current focus of R&D

- Advanced valve technologies
- Closed loop process control
- Scale up (6" print head)



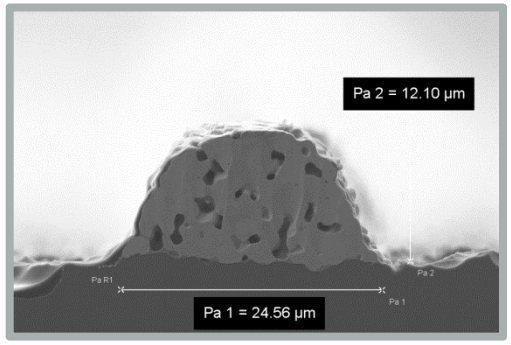
Parallel dispensed line end

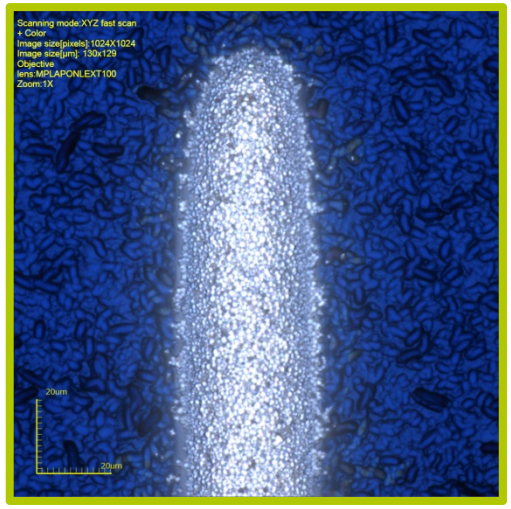
Fraunhofer ISE

PERC meets Parallel Dispensing
Summary & Outlook

Continuous Operation

- High process speeds (***v* = 800 mm/s**) possible
- Results on **PERC**: η_{max} = 21.3% and **21.4%** vs. 21.1% (reference) reached with two **commercial** screen printing pastes **of different suppliers**
- Record contact width $\boldsymbol{w_f}$ **= 25µm** with only $\boldsymbol{m_{Ag}}$ **= 48mg** wet paste lay-down, η = 21.2%





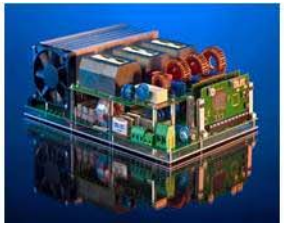
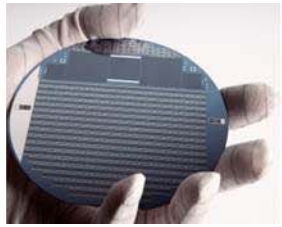
Intermittent Operation

- First process established (semi-contact) on lab tool
- Outlook: First cell processing and scale up

Fraunhofer ISE

Thank you for your attention! We will be back ☺




Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

Zusammen. Zukunft. Gestalten.

ESF Europäischer Sozialfonds für Deutschland

Europäische Union

eXIST Existenzgründungen aus der Wissenschaft

Fraunhofer-Institute for Solar Energy Systems ISE

Dr.-Ing. Maximilian Pospischil

www.ise.fraunhofer.de

maximilian.pospischil@ise.fraunhofer.de

Fraunhofer ISE