PERC MEETS PARALLEL DISPENSING

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

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PV Front Side Metallization
Looking for Innovative Production Tools

Screen Printing
- Screen fabrication
- Paste fabrication

Contact shape
- Electrical contact
- $\eta$ - gain
- Less Ag-laydown

Dispensing
- Device engineering
- Paste fabrication

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Dispensing at Fraunhofer ISE
Development of Multi Nozzle Print Heads

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**Single Nozzle Dispenser**

- **10 Nozzle Print Heads**

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**2010 2011 2012 2013 2014 2015 2016**

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**MWT-PERC:**

\[ \eta = 20.6\% \]

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**ASYS Dispense Platform**

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**6” Print Head**

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J. Specht et al., 25th EU-PVSEC, 2010
M. Pospischil et al., Energy Procedia 98, 61 (2016).
Goal: Integration in PV Metallization Lines
Dispenser as Drop-In-Replacement

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

From Q1/18 in PV-TEC again!

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

6” Print Head
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 $w_s = 40\,\mu m$
- Dispensed groups
  - Nozzle diameter $D = 35\,\mu m$
- Number of contact fingers
  - $N_f = 100$ (all groups)
- Ag-Paste variation
  - Two commercially available samples of different manufacturers
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
Latest PERC-Sampling in PV-Tec

$J_{sc}$ gain

- Significant gain
  \[ \Delta J_{sc} / J_{sc} \approx 1\% \]
- Substantially reduced shading

![Graph showing $J_{sc}$ (mA/cm²) vs. Screen Printed vs. Dispensed with different paste thicknesses: 27 – 30 μm, 33 – 35 μm, 45 – 48 μm.](image)
Latest PERC-Sampling in PV-Tec

$R_s$ and GridRes Analysis

- More homogeneous contact shape → more efficient material usage (Ag)
- Stable processing @ $w_f = 27\mu m$

$m_{Ag} = 110mg$

- = 100mg
- = 90mg
Latest PERC-Sampling in PV-Tec

Gain in Efficiency

- Less shading
  \[ \Delta j_{sc}/j_{sc} \sim 1\% \]

- FF and \( V_{oc} \) on similar level

- \( \Delta m_{Ag}/m_{Ag} = -19\% \)
  at similar \( R_s \)

\[ \Delta \eta/\eta \sim 1\% \]
\[ \eta_{max} = 21.4\% \]
Optimized for low Ag-consumption:
Same efficiency as screen printed reference (here: $\eta_{\text{max}} = 21.2\%$) @ $m_{\text{Ag}} = 48mg$ (incl. BB)!

$Pa_2 = 12.10 \mu m$

$Pa_1 = 24.56 \mu m$
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 $m_f < 30\text{mg}$

**M. Pospischil et al., Energy Procedia 55, 693 (2014).
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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 $\tau_y$
- Surface tension $\sigma$

Continuous Operation
- Inertia driven flow

Intermittent Operation
- Paste velocity drops dynamically
  $\rightarrow$ Surface effects dominate @ small nozzle diameters $D$

Mathematical Formulas:

\[ Re_y = \frac{\rho \cdot \bar{u}^2}{\tau_y} \]
\[ Ca_y = \frac{\tau_y \cdot D}{2\sigma} \]
\[ We = \frac{\rho \cdot \bar{u}^2 \cdot D}{2\sigma} \]
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)


→ 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)
PERC meets Parallel Dispensing
Summary & Outlook

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

Intermittent Operation
- First process established (semi-contact) on lab tool
- Outlook: First cell processing and scale up
Thank you for your attention! We will be back 😊