Seed layer printed contact formation for highly doped boron emitters of \textit{n}-type solar cells with front side junction

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Outline

- Motivation
- Metallization approach
- Measured specific contact resistance
- Shunting behavior of the contact formation
- First solar cell results
- Summary
Why *n*-type silicon for solar cell fabrication?

- Superior tolerance on common impurities (e.g. iron)
  
  ![Graph showing recombination lifetime vs. Fe concentration](image)
  
  \[ N_{A/D} = 1.5 \times 10^{16} \text{cm}^{-3} \]
  
  generation = 0.1 suns
  
  Auger limit included

- No light induced degradation due to B-O-pairs as in *p*-type Cz-Si
  
  ![Graph showing lifetime vs. illumination time](image)
  
  **P-doped n-type Cz-Si**
  
  \( 3.5 \ \Omega\text{cm} \)
  
  **B-doped p-type Cz-Si**
  
  \( 3 \ \Omega\text{cm} \)

*D. Macdonald, JAP 2005*  

*J. Schmidt, 22th EUPVSEC*
Boron Emitter Passivation
Atomic Layer Deposition of Al\textsubscript{2}O\textsubscript{3}

- Excellent performance at cell level
- Only very thin ALD layer necessary

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<tr>
<th>$V_{oc}$</th>
<th>$J_{sc}$</th>
<th>$FF$</th>
<th>$\eta$</th>
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<td>[mV]</td>
<td>[mA/cm\textsuperscript{2}]</td>
<td>[%]</td>
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Best cell 704.5 41.1 82.4 23.9*

*Confirmed at Fraunhofer ISE CalLab

Benick et al., new result
The solar cell structure

textured front side

front metallization

SiN$_x$ antireflection coating

passivation layer

$p^+$ emitter (boron doped)

$n$-type base

$n^+$-doped BSF

rear metallization
Firing stable passivation for $p^+$ doped boron emitters

**Emitter profile**

- Shallow industrial-type boron emitter:
  - $R_{sh} = 90 \, \Omega/sq$
  - Surf. conc.: $8 \times 10^{19} \, \text{cm}^{-3}$
Firing stable passivation for $p^+$ doped boron emitters

Al$_2$O$_3$ passivation

- Passivation by atomic layer deposited Al$_2$O$_3$
- Excellent $J_{0e}$ values of \( \sim 45 \, \text{fA/cm}^2 \) independent of firing temperature
- Generally allows for high-efficiency cells

![Graph showing emitter saturation current density vs. firing temperature](image-url)
Our front side metallization approach

- Necessities for high-efficiency cells regarding front side contact:
  - Low contact resistance
  - High lateral conductivity
  - Thin fingers

- A promising approach:

  2 layer metallization

- printed seed layer
- fired seed layer
- plated contact
The two layer metallization

Aerosol jet printed seed layer after electro-plating

- Thin seed layer: 17 µm width
- Total contact width after plating: 37 µm
- Plating leads to an excellent aspect ratio
The two layer metallization
Aerosol jet printing technique

- Contactless printing technique
- Generation of an aerosol
- Metal aerosol is focused on the substrate without getting into contact with the printing unit

➔ Successful application on $n^+$ emitters of $p$-type solar cells leading to 21.1%
Specific contact resistance on $p^+$ emitters

Test structures

- Specific contact resistance was measured by means of TLM measurements on
  - planar uncoated emitters
  - planar coated emitters
  - textured coated emitters

- Processing of the test structures:
  - Aerosol jet printed seed layer with silver ink (adapted $p$-SISC based on SISC ink for $n$-emitter, see talk M. Hörteis)
  - Contact firing at different temperatures in a rapid thermal processing furnace
  - Electro-plating of 10 µm silver
Specific contact resistance on $p^+$ emitters

**Emitter profiles**

Contact formation on:

- **Shallow industrial-type boron emitter:**
  - $R_{sh} = 90 \, \Omega/sq$
  - Surf. conc.: $8 \times 10^{19} \, \text{cm}^{-3}$

- **Deep high-efficiency type boron emitter:**
  - $R_{sh} = 135 \, \Omega/sq$
  - Surf. conc.: $6 \times 10^{18} \, \text{cm}^{-3}$
Specific contact resistance on $p^+$ emitters
Results on planar, uncoated emitters

- Shallow emitter (90 $\Omega$/sq):
  - $\rho_c < 1$ m$\Omega$ cm$^2$ at low firing temperatures
  - Excellent contact possible

- Deep emitter (135 $\Omega$/sq):
  - $\rho_c > 25$ m$\Omega$ cm$^2$
  - No adequate contact achieved
Specific contact resistance on $p^+$ emitters
Results on coated 90 $\Omega$/sq emitter

- Planar, Al$_2$O$_3$/SiN coated boron emitter:
  - $\rho_c \sim 1 \text{ m}\Omega \text{ cm}^2$ at a firing temperature of 730 °C
  - Contact firing through the Al$_2$O$_3$ (10 nm) / SiN$_x$ (60 nm) layer stack possible
Specific contact resistance on $p^+$ emitters
Results on coated 90 $\Omega$/sq emitter

- Planar, $\text{Al}_2\text{O}_3$/SiN coated boron emitter:
  - $\rho_C \sim 1 \, \text{m}$Ω$ \text{cm}^2$ at a firing temperature of 730 °C
  - Contact firing through the $\text{Al}_2\text{O}_3$ (10 nm) / SiN$_x$ (60 nm) layer stack possible

- Textured, $\text{Al}_2\text{O}_3$/SiN coated boron emitter:
  - $\rho_C \sim 1 \, \text{m}$Ω$ \text{cm}^2$ at a firing temperature of 750 °C
  - Minimum of $\rho_C$ at ~750 °C
Shunting behavior on 90 Ω/sq emitter
SunsVoc measurements

→ Significant shunting of the 0.3 µm deep emitter at firing temperatures >750 °C
Shunting behavior on 90 Ω/sq emitter
SEM image of the contact interface on the planar, coated emitter

- Fired at 700 °C
- Fired at 840 °C
First results on solar cells

- **Bulk:** 1 Ω cm $n$-type FZ-Si (size 20 x 20 mm²)
- **Rear:**
  - Phosphorus BSF
  - 2 µm evaporated Al
- **Front:**
  - Random pyramids
  - Shallow 90 Ω/sq emitter
  - Al₂O₃ (10 nm) / SiNₓ (60 nm) stack
  - Aerosol jet printed seed
  - Contact formation at 750 °C
  - Electro-plating of 10 µm Ag
- Low PFF (78%) due to insufficient edge isolation

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<td>645</td>
<td>37.7</td>
<td>76.0</td>
<td>18.5</td>
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Summary

- Very low specific contact resistance $\rho_C$ of $\sim 1 \text{ m} \Omega \text{ cm}^2$ on shallow 90 $\Omega$/sq emitter for firing the $p$-SISC ink through the $\text{Al}_2\text{O}_3$ (10 nm) / $\text{SiN}_x$ (60 nm) layer stack.

- No adequate contact with $\rho_C > 25 \text{ m} \Omega \text{ cm}^2$ on the deep 135 $\Omega$/sq emitter.

- Basically, the contact formation and the crystallite formation behavior seems to be similar to that on $n^+$ emitters.

- Cells efficiency of 18.5% reached on solar cell level with the shallow 90 $\Omega$/sq emitter.
Thanks for your attention!

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