Approaches to Metallization for Poly-Si/SiO$_x$ Passivated Contacts


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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.
Poly-Si/SiO$_x$ passivated contacts on Cz Si are focus of Si PV research at NREL since 2013 [1,2].

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<tbody>
<tr>
<td><img src="image" alt="Diagram of TOPCon process" /></td>
<td><img src="image" alt="Diagram of POLO process" /></td>
</tr>
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<td>Used for BSF of front-back cell</td>
<td>Used for emitter and BSF in IBC cell</td>
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[1] Lee et al., 40$^{th}$ IEEE PVSC (2014)
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### Why Poly-Si/SiO$_x$ ?

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<td><img src="image1" alt="Diagram" /></td>
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<tr>
<td>PECVD Poly-Si</td>
<td>LPCVD Poly-Si</td>
</tr>
<tr>
<td>Chem. SiO$_x$</td>
<td>Therm. SiO$_x$</td>
</tr>
<tr>
<td>c-Si</td>
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</table>
1. RCA-cleaned Cz-Si
2. 1.5nm thermal SiO$_x$
3. 20-50nm PECVD a-Si:H
4. Crystallization, 850°C 30min
5. 15nm ALD AlO$_x$
6. FGA, 400°C 1h
Poly-Si/SiO$_x$ at NREL

Before Ager
- Ti/Ag/Pd

p-type
- 745mV, 1.0fA/cm$^2$

n-type
- 714mV, 12fA/cm$^2$

After e-beam Ti/Ag/Pd

n-type
- 50ms
Outline

• Metal

• Spacer Layers
  o a-Si:H
  o TCO
  o Conducting Adhesive

• Summary
• Used in-situ doped LPCVD poly-Si
• Keep AlO_x on unmetallized side
• Initial iV_{oc}:
  o 735-740 mV (n-type)
  o 704-713 mV (p-type)

• Metals
  o 4nm Ti / 1µm Ag, thermal
  o 4nm Ti / 1µm Ag, e-beam
  o 1µm Al, e-beam
  o 1µm Al:1wt%Si, e-beam

• All metals 1µm thick, at 5A/s
• FGA: 200-400°C
Metals – $\Delta iV$ evaluation

- Quantify metallization damage from PL via implied voltage loss, $\Delta iV$, derived from PL intensity before and after metal:

$$\Delta iV = \frac{kT}{q} \ln\left(\frac{I_{after}}{I_{before}}\right)$$

- Measure on mirror to minimize effects of changing optics
Metals

**n-type**

- Δ$iV$ vs. FGA (cumulative)
- Metals: Al, Ti/Ag, Al:1wt%Si, Ti/Ag, thermal

**p-type**

- Δ$iV$ vs. FGA (cumulative)
- Metals: Al, Ti/Ag, Al:1wt%Si, Ti/Ag, thermal

**$\rho_c$**

- $\rho_c$ vs. FGA (cumulative)

**FGA (cumulative)**

- 50nm LPCVD Poly-Si
- 1.5nm thermal SiO$_2$
- c-Si
- 1.5nm thermal SiO$_2$
- 50nm LPCVD Poly-Si
- 15nm Al$_2$O$_3$
Metals - Conclusions

- Thermal evaporation less damaging
- E-beam damage of some metals anneals out
- Other metals kill contact before e-beam damage anneals out fully
- E-beam damage less severe for p-type (in ΔiV terms), but more prone to degradation upon FGA.
Spacers

• Metallization damage could be mitigated by spacer between poly-Si and metal.
• Can also improve light trapping
• Less sensitivity to reflectance of metal

Calculated maximum $J_{sc}$ for 150µm Si wafer cell assuming perfect textured front ARC

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<tr>
<th>Back structure</th>
<th>Ag metal</th>
<th>Al metal</th>
</tr>
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<tbody>
<tr>
<td>Flat rear, direct metal</td>
<td>41.58 mA/cm²</td>
<td>41.15 mA/cm²</td>
</tr>
<tr>
<td>Textured rear, direct metal</td>
<td>42.07</td>
<td>41.31</td>
</tr>
<tr>
<td>Textured rear, dielectric spacer (150 nm SiO₂)</td>
<td>42.61</td>
<td>42.50</td>
</tr>
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</table>

Ben Lee, 2015
Thin a-Si:H spacer reduces damage

Attributed to covering of pinholes in poly-Si

Negligible additional series resistance

Nemeth et al., 41st IEEE PVSC, Nemeth et al., MRS Spring Meeting 2015
• Evaporation of In-Sn alloy in O₂ ambient.
• Deposition of ITO without sputter damage (ΔiV<5mV)
• Expected to shield metallization damage
• Contact resistivities somewhat high
  o 23 mΩcm² to n-poly-Si
  o 37 mΩcm² to p-poly-Si
Spacers - Conductive Adhesive

- EVA with metal-coated microspheres [1,2]
- Bond metal to Si – Si doesn’t see metal preparation
- A single sphere bridges conductive adhesive (CA)
  - anisotropic conductivity
  - can conform to rough surface
- 10 area% microspheres yields <0.4 Ωcm$^2$ between Ag surfaces

Spacers - Conductive Adhesive

- PL imaging before and after metallization:
  - Ti/Ag/Pd stack, e-beam

- Metal transfer via NaCl and glass both maintain $iV_{oc}$ (<5 mV change)

- Same e-beam process directly on passivated contact $\rightarrow$ 120 mV drop
Spacers - Conductive Adhesive

- Ohmic IV curves

- \( \rho_c = 4 - 6 \, \Omega \text{cm}^2 \)

- \( \rho_c \leq 1 \, \Omega \text{cm}^2 \) feasible with more microspheres

- \( R_{c, \text{sphere}} = 3000 - 8000 \, \Omega \) (~0.1\( \, \Omega \) within sphere shell)

- \( \rho_c \leq 0.1 \, \Omega \text{cm}^2 \) requires improvement of microsphere/poly-Si contact
  - Increase effective contact area

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<th>Area% MS</th>
<th>( \rho_c )</th>
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<tbody>
<tr>
<td>1%</td>
<td>6 ( \Omega \text{cm}^2 )</td>
</tr>
<tr>
<td>4%</td>
<td>4 ( \Omega \text{cm}^2 )</td>
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• Pattern all metal for metallizing back-contact solar cells, and for interconnecting them, onto a backsheet
• Use CA to attach non-metallized cells. No shunts if area% low
• Creates opportunity for cheaper, and more efficient modules
- Pattern all metal for metallizing back-contact solar cells, and for interconnecting them, onto a backsheets
- Use CA to attach non-metallized cells. No shunts if area% low
- Creates opportunity for cheaper, and more efficient modules
• Thermal evaporation preferable to e-beam
• Some e-beam metals can work
  o Key factor is whether damage is annealed out before metal kills the contact
  o p-type fails sooner upon FGA
• Poly-Si can be shielded from direct metal contact with spacers
• Spacers can provide additional benefits
  o Improved optics
  o Streamlined module processing
Thank you for your attention

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