Biased Annealing for Industrial Mitigation of LeTID in Multicrystalline PERC Solar Cells

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Outline

• LeTID mitigation and contact resistance increase
• Hydrogen simulation and re-distribution
• Biased annealing to suppress contact resistance
• Process development
• Industrial prototype
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Fill Factor Losses during LeTID Mitigation

- Modified firing processes and subsequent thermal processing can mitigate LeTID
- Extended thermal processes post-firing lead to drop in fill-factors

0.15 FF loss $\rightarrow$ 20% loss in efficiency

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Fill Factor Losses during LeTID Mitigation

- Unstable at room temperature
- Investigation reveals this is due to an increase in front contact resistance

![Graph showing Fill Factor Losses during LeTID Mitigation](image)

- **353°C, 2 hours**
- **Before**
  - 1 mA RB
  - 1 mA FB
  - 5 mA FB
  - 25 mA FB
  - 50 mA FB

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>1 mA RB</th>
<th>1 mA FB</th>
<th>5 mA FB</th>
<th>25 mA FB</th>
<th>50 mA FB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.28±0.02</td>
<td>92±5</td>
<td>76±12</td>
<td>38±7</td>
<td>14.6±1.0</td>
<td>10.8±0.9</td>
</tr>
<tr>
<td>Gradient</td>
<td>32.34±0.07</td>
<td>40±8</td>
<td>48±13</td>
<td>31±7</td>
<td>34.7±1.2</td>
<td>35.5±1.3</td>
</tr>
</tbody>
</table>

Chan, C., et al., (2017), Solar RRL, 1(11), 1700129
Hydrogen Re-distribution

- Common assumption is that hydrogen is distributed near-uniformly throughout the bulk during metal cofiring
- With subsequent thermal annealing there is a driving force for hydrogen to move back to the surface
- Strong electric fields
- Amphoteric nature of hydrogen

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Initial Experiments

4 terminal I-V measurements, 0.2 V forward bias between measurements, 350°C, 4 hours
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Dependence on Applied Bias

In-Situ Observations

At room temperature

4 hours at 350°C

Degradation

Anneal: 400°C, 2 hours

Light Soak: 70°C, 1 sun illumination

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Process Development at UNSW

- Application of reverse bias during annealing can suppress FF loss due to $R_S$ increase (hydrogen induced contact resistance)
- Electric field prevents H building up near surface/contact regions $\rightarrow$ cells can be annealed for longer periods of time required to suppress LeTID
- We have designed and built a biased annealing prototype tool
  - 6” capable
  - Polarity of bias can be changed
  - Automatic IV measurement and bias control
Development Work – Temperature and Bias

- Light Soaking 70°C 1 sun
- High T, $R_S$ increase
- Low T, incomplete mitigation
- Apparent acceleration of recovery

80 min anneal

- 400°C 3V RB
- 350°C 3V RB
- Control
- 350°C No bias
- 400°C No bias
Development Work - Cooling

- Post-Anneal cooling critical to process
- Slow cooling without reverse bias → $R_S$ problems
- Slow cooling with switched bias → minimized degradation

![Graph showing the effect of switched bias and no bias on $V_{oc}$ ratio over time. The graph shows a decrease in $V_{oc}$ ratio with time for both switched bias and no bias conditions, but the switched bias shows a more gradual decrease compared to no bias.](image-url)
LeTID Mitigation: Finished Cells

- Combining biased annealing with switched cooling leads to optimal results
- Not only avoids any degradation but a slight boost to efficiency

**Graphs:**
- Relative change in Voc
  - Dark annealing with bias
  - Dark annealing without bias
  - Control
- Relative change in FF
- Relative change in Efficiency

**Images:**
- Initial 0h (after annealing)
- 21h LS
- 570h LS
- 1000h LS
- PL counts/s
Defects and Degradation Behaviour

<table>
<thead>
<tr>
<th></th>
<th>As Fired</th>
<th>Annealed</th>
<th>23h LS</th>
<th>1160h LS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bias</td>
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PL counts/s

23h LS
As Fired
1160h LS
As Fired
Industrial Prototype

- Process can be performed in modified commercial “coin-stacker”
- Already a viable commercial process
- Prototype installed at UNSW and undergoing modification
- Intermittent applied bias to reduce power consumption?
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Summary

- Many LeTID approaches lead to problems with contact resistance issues on finished cells
- Use of applied reverse bias during anneal can suppress these problems and lead to superior mitigation
- Can be implemented with minor modifications to existing, high throughput commercial tools

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