Cu-plated electrodes with green ns laser opening on n-type silicon solar cells

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Advance Technology Development Department
Motech Industries, Inc.
Motech Industries, Inc.

- Founded in 1983
- Established Solar BU in 1997

- Motech Americas
  - Delaware, US

- SNE
  - Jiangsu, China

- TY Fab
  - Taoyuan, Taiwan
  - Tainan, Taiwan

- Itogumi Motech
  - Hokkaido, Japan

- ITC
- Fab. I
- Fab. II
- Fab. V
- Fab. VI

Founded in 1983
Established Solar BU in 1997
A Leading Solar Cell Manufacturer

- 3.2GW cell production capacity in 2015
- No.5 in the world
- Smaller capacity of ingot growth, wafer slicing, module

Source: HIS, PV Suppliers Tracker 2015Q3
Outline

- Motivation
- Experimental Setup
- Results & Discussion
- Conclusion
Cell Efficiency; Market Share

- N-type cells provide higher efficiency
- Projected growth of market share for N-type cells
- Cost needs to be controlled

Reference: ITRPV 2016
Plating Application on Solar Cells

- Cu plating applicable to all types Si solar cells; more beneficial for n-type

**p-PERC**
- Plated Cu
- Ti/Cu
- Al BSF
- Dielectric

**HJT**
- Cu
- TCO i-Si/p-Si
- n-Si/i-Si TCO
- Rear metal electrode

**IBC**
- High Lifetime Silicon
- Optimized Thermal Process
- Plated seed/Cu electrodes
- Rear Dielectric Optimized for Passivation
- Improved Emitter Recombination Optimized Diffusions

**n-PERT**
- Boron emitter
- Phosphorous BSF
- Passivation layer
- Plated seed/Cu electrodes
Cell Structure and Process Flow

Schematic cross-section of the solar cell

- Texture
- Boron doping (emitter)
- Phosphorus doping (BSF)
- Front and rear passivation/capping
- Rear-side Ag printing and sintering
- Front side laser opening
- Plating Ni/Cu/Sn

Cell process flow
Applying a negative voltage to the rear contact of the cell, relative to the anode, making the cell in forward bias

Both Ni and Cu deposited using FBP
Lab Plating Equipment

- Simple homemade equipment used for FBP and electroplating
- Separate tanks for Ni, Cu, Sn
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Tuning of Laser Process

Tuning 532nm ns laser to achieve
- Removal of SiNx
- Thin line; uniform width
- Usable emitter
Ablation of SiNx

- EDS used to verify the removal of SiNx

<table>
<thead>
<tr>
<th>Elements</th>
<th>Atomic%</th>
</tr>
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<tbody>
<tr>
<td>Si</td>
<td>92.61</td>
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<tr>
<td>N</td>
<td>7.39</td>
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<table>
<thead>
<tr>
<th>Elements</th>
<th>Atomic%</th>
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<tbody>
<tr>
<td>Si</td>
<td>100.00</td>
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## Contact Opening Width

<table>
<thead>
<tr>
<th>Finger 1-5</th>
<th>Dielectric Layers Opening Width</th>
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<tbody>
<tr>
<td></td>
<td><img src="image1.jpg" alt="Image of dielectric layers opening width" /></td>
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<tr>
<td>Width (μm)</td>
<td>15.63</td>
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<tr>
<td>Ave. (μm)</td>
<td></td>
</tr>
<tr>
<td>Std. (μm)</td>
<td></td>
</tr>
<tr>
<td>Uniformity</td>
<td></td>
</tr>
</tbody>
</table>

- Contact opening width can be as low as 15μm by 532nm ns laser

CC Li, Metallization Workshop, May 2, 2016
<table>
<thead>
<tr>
<th>Finger 1-5</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Width (μm)</td>
<td>45.80</td>
<td>46.37</td>
<td>45.90</td>
<td>46.50</td>
<td>46.13</td>
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<tr>
<td>Ave. (μm)</td>
<td></td>
<td>46.14</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Std. (μm)</td>
<td></td>
<td>0.30</td>
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<tr>
<td>Uniformity</td>
<td></td>
<td>0.76%</td>
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</tbody>
</table>

- Achieved <50um finger width for plated electrodes
FBP Finger Shape

- Isotropic deposition
  - Overgrowth at the edges
  - Finger aspect ratio depends opening and thickness

(a) laser

(b) Ni

(c) Cu

(d) Cu

(e) Sn

~20μm

~22μm

~46μm

~12μm

~48μm

1kx

1.5kx

1kx

1kx
Highly Conductive Cu Fingers

- R-line measurement showed Cu fingers much more conductive

<table>
<thead>
<tr>
<th></th>
<th>R-line (Ω/cm)</th>
<th>Avg. (μΩ.cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag/Al paste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finger 1</td>
<td>0.389</td>
<td>0.381</td>
</tr>
<tr>
<td>Finger 2</td>
<td>0.409</td>
<td></td>
</tr>
<tr>
<td>Finger 3</td>
<td>0.398</td>
<td></td>
</tr>
<tr>
<td>Finger 4</td>
<td>0.378</td>
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</tr>
<tr>
<td>Finger 5</td>
<td>0.331</td>
<td>~2.7</td>
</tr>
<tr>
<td><strong>Avg.</strong></td>
<td><strong>0.381</strong></td>
<td><strong>~2.7</strong></td>
</tr>
<tr>
<td>Cu plating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finger 1</td>
<td>0.253</td>
<td>0.250</td>
</tr>
<tr>
<td>Finger 2</td>
<td>0.255</td>
<td></td>
</tr>
<tr>
<td>Finger 3</td>
<td>0.259</td>
<td></td>
</tr>
<tr>
<td>Finger 4</td>
<td>0.258</td>
<td></td>
</tr>
<tr>
<td>Finger 5</td>
<td>0.223</td>
<td>~1.9</td>
</tr>
<tr>
<td><strong>Avg.</strong></td>
<td><strong>0.250</strong></td>
<td><strong>~1.9</strong></td>
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</table>
Emitter Modification by Laser

- Laser process significantly changed emitter profile

![Graph showing boron concentration vs depth before and after laser process.]

**Before laser**
- 75 Ω/sq

**After laser**
- 95 Ω/sq
Emitter Experiments

- Various emitters tested for cell performance

**Efficiency (%)**
- Shallow
- Deep
- Heavy

**FF (%)**

**Jsc (mA/cm²)**

**Voc (V)**
Contact Resistivity

\( \rho_c \) of NiSi silicide contacts

- \( \rho_c \) of printed Ag contact is generally 1~3 m\( \Omega \).cm\(^2\).
- \( \rho_c \) of NiSi silicide contact can achieve 0.1~0.001 m\( \Omega \).cm\(^2\) level with 1E19~5E19 cm\(^{-3}\) surface doping concentration

Plated vs. Printed
21% Cell Efficiency

$I$-$V$ curve of Motech plated n-PERT solar cell

Best cell efficiency with different metallization

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Eff. (%)</th>
<th>FF</th>
<th>Voc (mV)</th>
<th>Jsc (mA/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag/Al paste</td>
<td>20.90</td>
<td>0.801</td>
<td>655</td>
<td>39.84</td>
</tr>
<tr>
<td>Ni/Cu/Sn</td>
<td>21.31</td>
<td>0.798</td>
<td>654</td>
<td>40.80</td>
</tr>
</tbody>
</table>

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Trend Chart of Cell Performance

- Acknowledgement: one-year grant from Ministry of Economic Affairs
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Conclusion

• Demonstrated forward bias plating of Ni/Cu with 532nm ns-laser contact opening process
  • 6” plated n-PERT solar cell reached efficiency 21.31%
  • Fine line capability
  • Highly conductive fingers

• Continued development for
  • Contact performance
  • Adhesion
  • Reliability
Thank You for Your Attention