Solar Technology;
Crystalline Silicon PV Solar Cells

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Director, C-Si Process Development

Applied Materials
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Agenda

- Applied Materials

- c-Si Manufacturing Process Flow
  Poly → Ingot → Wafer → Cell → Module

- Cost Reduction and Technology Roadmap
Applied Materials
Applied Materials Business Segments

SILICON SYSTEMS GROUP
Pursuing growth in emerging logic, emerging memory and packaging technologies

DISPLAY
Lowering cost and improving performance of displays

ENERGY & ENVIRONMENTAL SOLUTIONS
Lowering the cost of electricity

APPLIED GLOBAL SERVICES
Optimizing output and efficiency through service, equipment and automation software
PV Manufacturing Solutions Leadership

**Increased cell efficiencies**
**Higher productivity**
**Advanced automation**

**APPLIED HCT WAFERING SYSTEMS**
- Higher productivity
- Thinner wafers
- Consumables reduction

**APPLIED BACCINI CELL SYSTEMS**
- Increased cell efficiencies
- Higher productivity
- Advanced automation

#1 Equipment Provider

Source: Ranked by VLSI
c-Si Manufacturing Process Flow
## Silicon – Poly – Ingot Manufacturing

### Chemical Reaction
- **MG-Si**
- **Chemical Reaction with HCl**
  - SiCl₄
  - SiHCl₃
  - SiH₂Cl₂
- **Purification Conversion**
  - SiHCl₃
  - SiH₄
- **Thermal Decomposition CVD**

<table>
<thead>
<tr>
<th>Step</th>
<th>Sand</th>
<th>Purification (99%)</th>
<th>MG Si + HCl = TCS</th>
<th>High Purity Si</th>
<th>Multi c-Si: Casting</th>
<th>Mono c-Si: Ingot Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>Silica Extraction</td>
<td>Arc Furnace</td>
<td>CVD Reactor</td>
<td>Break up rods</td>
<td>Casting crucible with directional re-crystallization</td>
<td>Czochralski Growth</td>
</tr>
<tr>
<td><strong>Challenges</strong></td>
<td>Multi: material quality, defectively. Mono: Cost, Rs variation</td>
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</tr>
<tr>
<td><strong>Trends</strong></td>
<td>Polysilicon reactor size, Casting size 650kg → 850kg, Cast Mono</td>
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</tr>
</tbody>
</table>
## Ingot – Wafer Manufacturing

<table>
<thead>
<tr>
<th>Step</th>
<th>Croping and Squaring</th>
<th>Brick Finish</th>
<th>Mount Brick</th>
<th>Wafer Slicing</th>
<th>Pre-clean and Degluing</th>
<th>Singulation</th>
<th>Final Clean and Dry</th>
<th>Wafer Inspection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Wiresaw</td>
<td>Grind, chamfer</td>
<td>Manual</td>
<td>Wiresaw</td>
<td>Wet clean</td>
<td>Manual, automatic</td>
<td>Wet clean</td>
<td>Optical, electrical</td>
</tr>
<tr>
<td>Challenges</td>
<td>Reducing kerf loss, yield and productivity</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Trends</td>
<td>Thinner wafers, wafering productivity (structured/diamond wire)</td>
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</tr>
<tr>
<td>Applied Position</td>
<td>B5 Cropper, B5 Squarer</td>
<td>Shower BEAM™</td>
<td>B5</td>
<td>Wiresaw</td>
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</tbody>
</table>
# Cell Manufacturing

<table>
<thead>
<tr>
<th>Step</th>
<th>SDE, Texture Etch &amp; Clean</th>
<th>POCl₃ Diffusion</th>
<th>PSG Etch</th>
<th>ARC, Passivation</th>
<th>Front Busbar And Grid</th>
<th>Back Busbar</th>
<th>Back Metal</th>
<th>Co-Fire</th>
<th>Test &amp; Sort</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>Wet Etch</td>
<td>Furnace</td>
<td>Wet Etch</td>
<td>PECVD SiN</td>
<td>Ag Screen Print, Oven</td>
<td>Ag/Al Screen Print, Oven</td>
<td>Al Screen Print, Oven</td>
<td>Furnace</td>
<td>IV test</td>
</tr>
<tr>
<td><strong>Challenges</strong></td>
<td>Yield, uniformity, rising Ag cost, efficiency at cost</td>
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<tr>
<td><strong>Trends</strong></td>
<td>Factory productivity, efficiency improvement</td>
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<tr>
<td><strong>Applied Position</strong></td>
<td>Screen Print, Dryer</td>
<td>Screen Print, Dryer</td>
<td>Screen Print, Dryer</td>
<td>Test &amp; Sort</td>
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</tbody>
</table>

![Diagram of solar cell manufacturing process](image_url)
# Module

<table>
<thead>
<tr>
<th>Step</th>
<th>Stringing</th>
<th>Circuit Assembly</th>
<th>Layup</th>
<th>Laminate</th>
<th>Edge Trim and Butyl Tape</th>
<th>Frame</th>
<th>Junction Box</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>Automatic, Manual</td>
<td>Soldering leads</td>
<td>EVA, Tedlar™</td>
<td>Vacuum, cross-links the EVA</td>
<td>Flush against glass</td>
<td>Anodized Al, pressed or screwed</td>
<td>Spot welded</td>
<td>Flasher IV Test</td>
</tr>
<tr>
<td>Challenges</td>
<td>Stress from stringing operation, manual operations, material cost</td>
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<tr>
<td>Trends</td>
<td>Monolithic Module Assembly, alternative encapsulants</td>
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<tr>
<td>Applied Position</td>
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</table>
Making a Crystalline Si Cell

Poly Silicon Growth → Ingot → Wafering → Cell Processing → Module → Installation

SQUARER → CROPPER → WAFERING → PRINTER → DRYER → TEST&SORT
C-Si Technology Roadmap
The Predictable Cost Reduction of PV

Source: Navigant Consulting, NREL, Solarbuzz, pvXchange, Morgan Stanley, New Energy Finance
Crystalline Silicon Technology Roadmap

**GEN 1**
- Front / Back Contact
- Conventional Cell
- 2010

**GEN 1.5**
- Selective Emitter (SE) Shallow Emitter
- Double Print (DP)
- 2011

**GEN 2**
- MAP™ Yield Metrology
- 2-Side Passivation
- Optimal Light Trapping
- Back Contact
- 2012
- 2013
Example 1: Selective Emitter

- Homogeneous emitter region requires compromise
- Good junction performance
- Low resistance to the front silver grid

- Selective emitter decouples the regions
- Lower dopant concentrations of the field region help reduce recombination
- Higher dopant concentration emitter improves ohmic contact
Example 2: Two Side Passivation

Conventional Cell

- Front side gains through reducing shading, optimizing emitter and optics

Backside Passivation

- Reduces recombination losses
  - Repairs defects and dangling bonds
  - Reduces charge effect
  - Negative Al₂O₃ film charge repels electrons
  - SiN improves barrier properties
  - Al₂O₃ low index of refraction reflects light back to bulk
Summary

- Applied Materials is the largest equipment supplier in the PV industry
- We mainly deal in the wafer and cell production technologies
- Module cost reduction has driven the growing market (now at ~30GW/year)
- Now BOS (balance of system) costs and module efficiency are coupled to achieve continued cost improvements.
- Applied Materials is developing cost effective materials, tools and services to increase cell and module efficiency to continue to drive down costs for our customers.