Emerging Technologies in the Solar Landscape: Can Thin Films Play a Role?

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Significant Advantages of Thin Film Solar vs. x-Si

- Potential for lower $/w than crystalline silicon (x-Si):
  - Less material required
  - Simplified fabrication process
  - Cheaper manufacturing equipment

- New products become possible:
  - Flexible modules
  - Lightweight modules
  - Awnings, clothing, roll-up PV blinds, portable devices
  - Partially transparent devices for BIPV

- Improved performance at lower light levels

- Less power lost at high temperatures

SOURCE: Xunlight
SOURCE: Konarka
SOURCE: G24i
SOURCE: Solarmer
Thin Films May Surpass x-Si Efficiencies...

...but it will take time and resources.
Thin Films Have Come a Long Way In Reducing Costs

- Applied Materials SunFab™
- Leveraging knowledge from flat panel display technology
- 5.7m² modules
- Tandem junction a-Si / mx-Si layers
- Targeting $0.71/W production
- Installation costs also reported lower

SOURCE: Applied Materials
Need to Address Challenges to Wide-Scale Deployment

- Efficiencies still lag those of crystalline silicon
- Degradations of modules and material in the field
- Process yields
- Availability of materials
  - Concerns for CIGs and CdTe

Delamination of thin film cells.


Challenges in the Field vs. x-Si

- It is more challenging to make thin film modules that can survive 30 years outdoors compared to x-Si:
  - Cells are not surrounded by encapsulant
  - Laser scribes can provide a route for water to wick into devices
  - Delamination between glass and TCO
  - Many thin film materials tolerate less moisture than x-Si before problems become apparent
  - More distinct layers over which delamination problems can occur

SOURCE: DayStar Technologies
Addressing Moisture Absorption in Thin Film Modules

- Edge sealing for glass modules
- Improved encapsulation for flexible modules
  - Use of organic/inorganic materials developed for OLED
  - Nano-particle pore sealing technology

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Moisture permeation rate (g/m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical barriers</td>
<td>1E-02 to 1E-03</td>
</tr>
<tr>
<td>Multilayer</td>
<td>1E-05</td>
</tr>
<tr>
<td>Nano-particle pore sealing</td>
<td>As low as 1E-08</td>
</tr>
</tbody>
</table>


SOURCE: *Semiconductor International*, 5/1/08
More Suitable Module Testing Standards Are Needed

- **Standard “Peak Power” Conditions:**
  - 1000 W/m²
  - Irradiation normal to module plane
  - am 1.5 spectrum
  - 25 °C

- **Real-Life Conditions:**
  - Light intensity changes with time of day and seasons
  - Diffuse light (cloudy, early or late in day)
  - Angle of irradiation changes
  - Efficiency of modules decreases as they heat up under high irradiation

- **Most Important Economic Metric:** Total kWh Generated by System

### Electrical Characteristics

<table>
<thead>
<tr>
<th></th>
<th>SX 3200</th>
<th>SX 3195</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power (P_{max})</td>
<td>200W</td>
<td>195W</td>
</tr>
<tr>
<td>Voltage at P_{max} (V_{mp})</td>
<td>24.5V</td>
<td>24.4</td>
</tr>
<tr>
<td>Current at P_{max} (I_{mp})</td>
<td>8.16A</td>
<td>7.96A</td>
</tr>
<tr>
<td>Warranted minimum P_{max}</td>
<td>182.0W</td>
<td>177.5W</td>
</tr>
<tr>
<td>Short-circuit current (I_{sc})</td>
<td>8.7A</td>
<td>8.6A</td>
</tr>
<tr>
<td>Open-circuit voltage (V_{oc})</td>
<td>30.8V</td>
<td>30.7V</td>
</tr>
<tr>
<td>Temperature coefficient of I_{sc} (0.065±0.015)%/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature coefficient of V_{oc} (-111±10)mV/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature coefficient of power (-0.5±0.05)%/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOCT (Air 20°C; Sun 0.8kW/m²; wind 1m/s)</td>
<td>47±2°C</td>
<td></td>
</tr>
<tr>
<td>Maximum series fuse rating</td>
<td>15A</td>
<td></td>
</tr>
<tr>
<td>Maximum system voltage</td>
<td>600V (U.S. NEC rating)</td>
<td></td>
</tr>
</tbody>
</table>

*SOURCE:* BP Solar SX3200 200W module data sheet
Thin Film Modules Can Perform More Favorably Than x-Si

- Low/Diffuse Light:
  - Some thin film modules become more efficient
  - x-Si becomes less efficient

- Increased Temperature:
  - Power output of x-Si modules typically decreases by 0.5% / °C above nominal operating temperature

![Graph showing relative outdoor module efficiency vs. irradiance](image.png)

### Table - Temp Coefficient / °C

<table>
<thead>
<tr>
<th>Product</th>
<th>Temp Coefficient / °C</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>mc-Si</td>
<td>-0.47%</td>
<td>Schott literature</td>
</tr>
<tr>
<td>a-Si (Triple Junt)</td>
<td>-0.31%</td>
<td>NREL</td>
</tr>
<tr>
<td>CIGS</td>
<td>-0.60%</td>
<td>Shell literature</td>
</tr>
<tr>
<td>CdTe</td>
<td>-0.20%</td>
<td>First Solar litterature</td>
</tr>
<tr>
<td>X-Si</td>
<td>-0.47%</td>
<td>Schott litterature</td>
</tr>
<tr>
<td>a- Si (Tandem Junt)</td>
<td>0.00%</td>
<td>Sanyo brochure (a-Si)</td>
</tr>
</tbody>
</table>

**SOURCE:** IBIS report for XsunX: Levelized Cost of Electricity
Performance of Thin Film Modules

- Performance difficult to compare
- Rating kWh/kWp relates generated power to nameplate power
- Developing better metrics to compare thin films with x-Si on “energy harvesting” capabilities

Test facilities at ISET, Kassel

Summary

- Thin films represent a promising opportunity:
  - Possibility of lower costs
  - Opportunity to significantly improve efficiencies

- Technical challenges exist and need to be worked out:
  - Moisture protection is badly needed
  - New testing standards and methodologies must be developed and utilized