Technologieentwicklung für Dünnschicht- und kristalline Silizium-basierte Photovoltaik

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Vice President European Photovoltaic Industry Association (EPIA)
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Workshop “Photovoltaic meets Microtechnology: Chancen und Herausforderungen”
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Erfurt
Safe Harbor Statement

This presentation contains forward-looking statements, including those relating to Applied Materials’ growth opportunities, product capabilities, acquired businesses, cost-per-watt-reduction strategy, efficiency roadmap, solar contracts, and financial goals. These statements are subject to known and unknown risks and uncertainties that could cause actual results to differ materially from those expressed or implied by such statements, including but not limited to: demand for solar products, which is subject to many factors, including global economic and market conditions, government policies and incentives relating to renewable energy, technological innovations, the cost of competing sources of energy, and evolving industry standards; the performance of acquired businesses; Applied’s ability to (i) successfully develop, deliver and support its broad range of products and expand its markets and develop new markets, (ii) effectively manage its resources and production capability, (iv) accurately predict the characteristics of, and capitalize on opportunities in, emerging markets, and (v) attract and retain key employees; and other risks described in Applied’s SEC filings. All forward-looking statements are based on management’s estimates, projections and assumptions as of October 30, 2008, and Applied undertakes no obligation to update any such statements.
Vision: To lead the nanomanufacturing technology revolution with innovations that transform markets, create opportunities, and offer a cleaner, brighter future to people around the world

- Annual Revenue (2007) – Approx. $9.7 Billion
- Worldwide Employees – >14,000
- Worldwide Locations – 18 Countries
Energy and Environmental Solutions

Solar
- PWS + Baccini
  - cSi work cells

Lighting
- TF

Web
- LED
- OLED

Glass
- R2R
- architectural applications

New Technologies
- Nanotech
- TF battery
- Electrochromic windows

SunFab® (aSi / μc complete lines)
Enabling All Forms of Solar PV

BUSINESS MODEL

Preeminent supplier of equipment and technology to the solar industry

Provide Equipment and Technology Solutions

Wafer Based Solar

Thin Film Solar

Provide Integrated Manufacturing Lines

END MARKET APPLICATIONS

Residential Rooftop

Commercial Install

Utility Scale Solar
Technology Evolution

Module Efficiency [%]

Module price (rel. Units)

@ - (5 to 9) % price decrease per year

ref: W. Hoffmann personal estimates
VLSI/DRAM

$\mu$/W module price

GW accumulated

%price decrease by doubling cumulative volume

$\mu$/W module price

~28% reduction for doubling of total volume

Cumulative Bits

Experience factor

1.8 GW/yr 2005

6 GW/yr 2010 F

70 GW/yr 2020 F

340 GW/yr 2030 F

$10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ $1$ $10$ $100$ $1000$ $10000$

0.1

1

10

100

1000

10000

10$^5$ 10$^7$ 10$^9$ 10$^{11}$ 10$^{13}$ 10$^{15}$ 10$^{17}$ 10$^{19}$


20% price decrease by doubling cumulative volume

Forecast

%reduction for doubling of total volume

15%

18%
c-Si: Focus on High Value Processes

- Thin Wafer Processing
- High Productivity Systems
- Cell Efficient Processes
- Low Manufacturing Cost

Applied’s 2008 c-Si SAM ~42% of c-Si TAM
c-Si Technology

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
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<tbody>
<tr>
<td>Wafer [µm]</td>
<td>450</td>
<td>300</td>
<td>180</td>
<td>100</td>
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<tr>
<td>Kerf loss [µm]</td>
<td>500</td>
<td>250/0</td>
<td>150/0</td>
<td>100/0</td>
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<tr>
<td>Cell efficiency [%]</td>
<td>12 – 14</td>
<td>14 – 17</td>
<td>17 – 22</td>
<td>19 – 24</td>
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<td>30 - 40</td>
<td>8 - 16</td>
<td>5 - 9</td>
<td>1,5 - 3</td>
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<tr>
<td>Module</td>
<td>Long term stable, low cost/m² technology</td>
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In the long run integrated manufacturing of thin wafers (100 µm or less) and subsequent cell and laminate making is probably the most effective route.
Industry Leader: Applied Precision Wafering Systems

<table>
<thead>
<tr>
<th>Step Names</th>
<th>Poly Silicon</th>
<th>Ingots</th>
<th>Wafering</th>
<th>Cell Production / Manufacture</th>
<th>Laminate</th>
<th>Module</th>
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<td>Metallization</td>
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<td>Edge Isolation</td>
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<td>Inspect / Test</td>
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- High silicon savings, high throughput, high load capacity

Over 720 systems shipped
Improve Material Efficiency: Thin Wafers

PV Wafering Roadmap

Polysilicon Production (Mton)

Cost / m²
Watt / m²

Data sources:
- Wafering: S. Schneberger, April 2007
- Polysilicon: A. Bjørseth, June 2007
### ATON: Drive Down Cost/Area Through Scale

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- **Throughput:** >3,800 wafers/hr
- **Capacities to:** 100MW
- **MTBC:** >10 days
- **Silane free processing**

**Highest productivity c-Si passivation/ARC technology**
Production Uniformity and Wafer Binning

Cost / m²
Watt / m²

High yielding technology
Conventional Approach

Production Quantity

Cell Efficiency

External Use
SiN:H Film Uniformity
(Coating width 1600mm)

- Uniformity of SiN thickness through target life: < ± 2.3%
- Uniformity of refractive index through target life: < ± 0.01
Cell Efficiency of TwinMag Sputtered SiN:H

Optimized PECVD results

Optimized results for sputtered SiN:H better than PECVD results

I-V curve parameter results of solar cells on neighboring wafers

Flow rate of ammonia

Cell Efficiency [%]

Voc [mV]

PECVD

TwinMag Sputtering

- Voc
- cell efficiency

15.0

14.7

14.4

14.1

13.8

13.5

610

605

600

595

0
Industry Leading Solutions: Baccini

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**DRIVERS:**
- High yield and uptime
- High throughput
- Thin wafer handling
- Uniform fine lines

Over 350 systems/lines shipped
Basis for SoftLine (SL): minimize handling

- Comparison “Heavy Handling” 2,200 Wph
  “Soft line” 1,450 Wph (@156 mm)

- Min. breakage (0.2 %), demo 100 µm-wafer

- Min. stop time (10 sec avg. stop time)
SL: Screen Printing Module

- ‘Rotary’ table concept
- 4 actions same time slot
- Integrity check load/unload
- SP motorized head
  - x,y,z,theta alignment
  - 5 linear motors
- 4-6sec. screen replacement

a) Wafer position detection and check
b) Screen Print
c) Wafer check and unload
d) Wafer rejection
SL: Centering Device for Wafer Alignment

- 3 motors integrated
- No contact at wafer edges
- Linear guide with integrated encoder
- In-line mount before critical steps
  - Buffering
  - AOI
  - Testing/Sorting
Substrate Size Expansion in LCD

Gen 2
370 x 470mm

Gen 2.5

Gen 3

Gen 3.5

Gen 4

Gen 5

Gen 6

Gen 7

Gen 8 = 5.7 square meters

2.6 meters

2.2 meters

4 up 10.4”

6 up 12.1”

6 up 15 ~ 17”

6 up 19 ~ 24”

6 up x 37” wide

6 up x 52” wide
SunFab Capabilities: Films

- Single Junction (SJ)
  - Amorphous silicon
  - 6-7% Efficiency

- Tandem Junction (TJ)
  - Amorphous and Microcrystalline silicon
  - 8-10% Efficiency

- Single Junction (SJ)
  - Amorphous silicon
  - 6-7% Efficiency
TCO Glass Choice and Washing

- TCO = transparent conducting oxide as top electrode
- Doped Tin Oxide – commercially available – ca. 10 ohm/square
- Best to use textured “hazy” films to maximize light scattering
- Standard soda lime glass for lowest-cost single-junction devices
- Low-Iron soda lime glass for higher-efficiency tandem junctions
- Control the glass cleanliness from the glass line to the solar plant
- Wash with a hot soap solution; rinse with hot DI water
Laser P1 Scribe Process

- TCO layer (P1 scribe)
  - Use IR light (1064nm)
  - Scribe from glass side, i.e. laser beam passes through the glass
  - Width of scribe is optimization between leakage current and lost aperture area of module
  - Scribe alignment marks for the next two layers
  - Scribe panel serial number and bar code
  - Wash after scribe to remove any scribing debris
PECVD Deposition of A-Si and Micro-Si layers

- Plasma-enhanced chemical vapor deposition cluster tool
- Substrate temperature ca. 200ºC
- SiH4 + H2 + dopants
- Deposition rates & handling timing for 20 sheets/hour
- Separate deposition chambers for p and in layers
- NF3 cleaning of chambers
Laser P2 Scribe Process

- Absorber layer (P2 scribe)
  - Use green light (532nm), transparent to TCO
  - Scribe from glass side
  - Scribes registered with vision system
  - Needs a separation between scribe P1 and P2 for better contact between metal layer and TCO
  - Process sensitive to laser power
PVD – Back Contact Deposition

- AZO (Al-doped Zinc Oxide – 1000A thick – enhances back reflection)
- Cr (Chromium layer 20A thick – glue for the silver layer)
- Ag (Silver layer 2000A thick – reflector and current carrier)
- Ni (Nickel layer 500A thick – environmental protection)
Laser P3 Scribe Process

- Metal Contact layer (P3 scribe)
  - Use green light (532nm), transparent to TCO
  - Scribe from glass side
  - Scribe on both absorber and metal layers
  - Needs a separation between scribe P2 and P3 to avoid the damage of connection
Laser Scribe Process

400µm spec
SunFab™ Layout

- Quality Assurance
- Shunt Busting
- Cut & Break
- Buss wire Installation Tool
- Seamer and Edge Delete
- Washer 3
- PVB Cutter
- L Rack
- Loading Robot
- Washer 1
- Hand Seam
- Laser Scribe P1
- A Rack
- Accumulator gantry
- Storage Box
- Dry Washer
- PVB Chuck
- Lamination
- A Rack
- Autoclave
- Storage Box
- PVB Chuck
- Loading Robot
- Washer 4
- Dry Washer Solar Simulator
- Junction Box Installation Tool
- A Rack
- CVD Loader
- Storage Box
- CVD
- Manual Module Unloader
- Accumulator gantry
- Storage Box
- SunFab™ Layout
Future Growth of the Global PV Solar Electricity Market in GWp and bn€ turnover

PV Power installed, GWp/a

Market, billion €/a

- Module level range depending on experience factor (15% - 18%)
- Fab-invest level (decrease: ~10% every 5 years)
- Upper bound: c-Si, full production chain
- Lower bound: thin film

ref: W. Hoffmann personal estimates
Share of PV Technologies

Yearly installed PV Power [GW] | 7 | 25 | 60 | 200 | 300
--- | --- | --- | --- | --- | ---
2010 | 100% | 80% | 60% | 40% | 20%
2015 | 60% | 80% | 100% | 40% | 20%
2020 | 40% | 80% | 60% | 100% | 20%
2025 | 20% | 80% | 60% | 40% | 100%
2030 | 0% | 80% | 60% | 40% | 100%

Ref: W. Hoffmann personal estimates
Solar Learning Curve: Module Cost/Watt

- Historical Prices
- 1980: $1.00/W @ >100 GW
- 2007: $1.00/W @ <20 GW
- Thin Film: $1.00/W @ >100 GW
- Polysilicon shortage

$ \text{Production / Watt} = \frac{\text{Cost / m}^2}{\text{Watt / m}^2}$

<table>
<thead>
<tr>
<th>Year</th>
<th>Production line size (Megawatts per Year)</th>
<th>Lines Per Factory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0.5 (1980)</td>
<td>2</td>
</tr>
<tr>
<td>2005</td>
<td>50 (2005)</td>
<td>4</td>
</tr>
<tr>
<td>2010</td>
<td>100 (2010)</td>
<td>10</td>
</tr>
<tr>
<td>2010+</td>
<td>1000 (2010+)</td>
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</tbody>
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Source: Adapted from National Renewable Energy Laboratory
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</tr>
</thead>
<tbody>
<tr>
<td>Fossile (coal, gas)</td>
<td>4 - 4.5</td>
<td>6 - 7</td>
<td>6.5 - 9</td>
</tr>
<tr>
<td>Nuclear (PWR, HTR, FBR)</td>
<td>4 – 6</td>
<td>3.5 – 7</td>
<td>3.5 - 6</td>
</tr>
<tr>
<td>PV solar electricity (south/north)</td>
<td>20/40</td>
<td>5/10</td>
<td>3/6</td>
</tr>
</tbody>
</table>

*ref: EURELECTRIC & W. Hoffmann personal estimates*
World Electricity Production Forecast

TWh³ / year

1 assuming 1.4% increase per year (source: IEA WEO 2004 “World Alternative Policy Scenario”) and starting at 17,400 TWh world electricity production in 2004 (source: BMWi “Zahlen und Fakten – Energiedaten”, 2006)

2 assuming average of 1200 kWh yearly electricity production per installed kWp module power (own estimate)

3 TWh = Terawatt-hour = 1 billion Kilowatt-hours
