U.S. PV Manufacturing and Opportunities for Florida

Winston V. Schoenfeld  
Director, PVMC-FL

Associate Professor  
Florida Solar Energy Center & CREOL  
University of Central Florida  
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Selective Emitter Process

The inline system for producing selective emitters with the aid of inkjet printing technologies is integrated into the Single Side Edge Isolation and PSG equipment.

Basic concept of the Selective Emitter

With this combined printing and etching technology, the high phosphorous doping layer is selectively etched onto the cell and only maintained in those places where contacts are subsequently printed. For this purpose a wax mask is applied in inkjet printing. The utilization concept of the selective emitter increases the efficiency of the solar cell by up to 0.8%.

Reduction of the doping concentration for the active emitter area

The active emitter area

Higher doping concentration underneath the fingers and bus bars compared to the optical active cell area

The DoD Inkjet Printer is required in combination with the SE-process for digital printing of the etch masks.
Manufacturing Share of Gross Domestic Product

- U.S.: 11.7%  China: 25%
- By Comparison it was 28% in U.S. in 1950’s

- Note: Not due to reduced manufacturing, but rather slower growth rate.
- Why care? General estimates are that every new manufacturing job generates 5 other jobs in the economy.
The History and Status of U.S. PV Manufacturing

5-Year CAGR of ~ 32%

5-Year CAGR of ~ 54%
Manufacturing is not just Cells/Modules

Note: U.S. had $247M trading surplus with China

Market Share

40%
3%
4.6%
3%

** Taken from GTM Research/SEIA Publication
Government Support of PV Manufacturing (loan guarantees)

- **U.S. - Section 1705 of the 2005 Energy Policy Act**
  - $15.6B in loans ($10.5B for solar), but ~$1B in 2010

- **China - China Development Bank (CDB)**
  - $30B in 2010 loans

Data from Grist.org and Greentech Solar
Is there another way to maintain/grow U.S. PV market share?

- Government Loan Guarantees are not enough
- Need Multiple support structures
  - Capital costs
  - Bankability (finance)
  - Strong/talented work force
  - Proximity to innovation
- Loan Guarantees address first item
- Is there another complimentary route for U.S. PV market share growth?
Can technical innovation drive U.S. market share?

**Question:** Why has Intel led IC industry for 19 years?

**Answer:** 3-7 years Transistor technology lead – 50-100% pricing power.

### "Transistor Design" Advantage

- SEMATECH Led Industry to ALD HfO$_2$ as High-k – Intel adopted novel integration
- IMPACT: Intel’s competitive edge results in ~ $100B revenue from high-k HfO$_2$

*TSMC – “Taiwan Semiconductor Manufacturing Company”*
My experience - A snapshot of the LED industry

- In 2000, there were many U.S. LED companies
- Common price of blue LED chip $0.20 - $0.30
- Two years later price was $0.05 - $0.10

- **Cause:** Despite rapid market growth, Asian manufacturing (i.e. supply) grew faster.
- **Result:** Only handful of major LED U.S. manufacturers remain.

- **Common Denominator:** All invested in technical innovation, allowing them to stay ahead of commodity curve.
Some History from Semiconductor Industry

“The most significant finding of the Task Force is that U.S. technology leadership in semiconductor manufacturing is rapidly eroding and that this has serious implications for the nation’s economy and immediate and predictable consequences for the Defense Department.”

- Defense Science Board Task Force on “Semiconductor Dependency” - February 1987

![Graph showing the trend in semiconductor market share between U.S. and offshore sources. The graph illustrates the decline in U.S. market share and the rise in offshore market share post-SEMATECH formation in 1988.]
U.S. Photovoltaic Manufacturing Consortium (PVMC)

- DOE decided it needed a similar SEMATECH model for the PV Industry
- Led by SEMATECH in partnership with CNSE (College of Nanoscale Science and Engineering) and UCF (University of Central Florida)
- Overall investment of ~$300M over 5 years from DOE and matching funds
- Initial focus on CIGS and cSi technology and manufacturing solutions
Key: Establishing **Collaborative** Consortiums

- PV Industry is historically fragmented
- How do you get consortium members – even direct competitors – to work together?

Consortium Program

**Distributes Risk & Cost**

**Accelerates Progress**

Company A  Company B  Suppliers
Example Program: 50µm SE cSi Cell

**Industry**
- 50 µm mono cSi Wafers
- Non-contact metallization equipment for Front Grid and LBC
- Backside passivation deposition equipment (ex. APCVD)
- New stringing/tabbing equipment and processes for thin wafers
- Electroplating chemistries and baths

**Academia**
- Rheology studies for nanoparticle seed layer
- Front grid geometry optimization
- Seed layer optimization
- LBC studies (opening method, diameter/spacing, etc…)

**National Labs**
- Reliability studies
- Validation of performance
- Field testing

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**Program $/Wp Reduction Targets:**
- Metallization >$0.15/Wp
- Wafer $0.40/Wp

**Cost, SUS per Wp**

- **2010 Module**
- **Target Areas**
- **BFT Goals**
- **$1/W**

- Ag-reduced / Ag-free grid
  - Cost Reduction: $0.15/Wp
  - Efficiency Increase: 0.3-0.6%

- Advanced Selective Emitter
  - Efficiency Increase: 0.4-0.8%

- APCVD Passivation
  - Efficiency Increase: 0.2-0.3%

- 50 µm mono-Si Wafer
  - Cost Reduction: $0.40/Wp

- Local Back Contact and BSF
  - Efficiency Increase: 0.3-0.4%

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**PVMC**

10 November 2011
What is a β-Site?

Example Project: Integration of inline carrier lifetime mapping after P-diffusion, communicating with MES using SEMI PV 02 Standard
Initial PVMC cSi Program Areas

1. In-line/Off-line Metrology

**Primary Goals**
- Identify critical industry needs in metrology and rank
- Develop projects to demonstrate new cSi metrology technologies
- Transition new metrology technologies into pilot and manufacturing lines

**Current 5-Yr Program Area Goal (revision expected by WG)**
- >1,100 wf/hr in-line tool, reducing yield loss such that cost of insertion is offset completely

2. New Feedstock/Wafering Methodologies

**Primary Goals**
- Identify necessary feedstock/wafering targets for $/W
- Establish cSi feedstock/wafering programs to accelerate transition of new technologies into mainstream manufacturing
- Provide and foster process, test, and demonstration activities to validate new technologies and identify technical barriers

**Current 5-Yr Program Area Goal (revision expected by WG)**
- Demonstrate silicon usage efficiency < 3g/W and cSi wafer cost reduction of >50% to below $0.25/W.

*These two program areas are currently supported in FL through $14.3M of DOE and industry/partner matching funding*

**So...How are projects identified?**
Projects driven by identified areas of need

- Consortium members identify program area projects (working groups)

<table>
<thead>
<tr>
<th>Cell Projects</th>
<th>Ranking Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1 Selective Emitter (inkjet/self-aligned, etc.)</td>
<td>54</td>
</tr>
<tr>
<td>P2 SiO$_2$/SiN ARCs (Multi-layer or graded SiON)</td>
<td>53</td>
</tr>
<tr>
<td>P3 Advanced Cell Structures (all back metal, emitter/metal wrap-through, n-type wafers)</td>
<td>44</td>
</tr>
<tr>
<td>P4 Ag Contacts (non-contact, lower width, etc.)</td>
<td>41</td>
</tr>
<tr>
<td>P5 Ag-free Grid Metallizations &amp; Electroplating</td>
<td>39</td>
</tr>
<tr>
<td>P6 Texturing (IPA free, dry texturing, high aspect ratio, etc.)</td>
<td>39</td>
</tr>
<tr>
<td>P7 Enhanced Surface Passivation Methods (aqueous ozone)</td>
<td>39</td>
</tr>
<tr>
<td>P8 Correlation Study (offline data to yield, h, performance distribution, etc.)</td>
<td>39</td>
</tr>
<tr>
<td>P9 In-line Metrology Tool Development</td>
<td>39</td>
</tr>
<tr>
<td>P10 Thin Wafer Handling, Statistics, &quot;Moore's Law&quot; cost model for PV</td>
<td>39</td>
</tr>
<tr>
<td>P11 Simulation: w/f thickness, bulk doping, emitter doping, Rco</td>
<td>35</td>
</tr>
<tr>
<td>P12 Integration of n-type or Ga doped p-type wafers into existing processes</td>
<td>35</td>
</tr>
<tr>
<td>P13 2D and 3D modeling of advanced cell structures (local contacts, adjacent n and p regions)</td>
<td>23</td>
</tr>
<tr>
<td>P14 Grain boundary and surface passivation</td>
<td>23</td>
</tr>
<tr>
<td>P15 Alternate surface passivation techniques (e.g. Silicon carbide, negative charge dielectrics)</td>
<td>15</td>
</tr>
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</table>

- Identical paretos for feedstock/wafering, modules, and manufacturing productivity.

- Program area ranking allows prioritization of projects and selection of asset allocation.
So….What is the Unique Opportunity for Florida ???

- Currently, Florida is one of only 2 states running the first U.S. PV manufacturing consortium
- Florida houses the cSi arm of the PVMC – a conversion technology that has maintained 80% market share for over a decade.

- We have the potential to grow into something much larger….
Supply Chain Strength in the U.S.

PVMC-FL can build from existing U.S. leadership in several areas of the cSi PV supply chain – smaller barrier for growth and job creation.

**R&D Partners**
- IBM
- NREL
- ORNL
- SRC
- NIST
- ASU
- SUNY
- UCF

**Material Suppliers**
- MEMC
- ATMI
- 1366
- Crystal Solar
- JT Baker
- Saint Gobain
- Solsil
- Dow

**Equipment Suppliers**
- Schmid
- Spire
- TEL
- Roth & Rau
- Varian
- Ulvac
- Consarc

**Metrology Suppliers**
- Semilab
- Boeing/Spectrolab
- FEI
- Keithley
- Agilent
- Newport
- Ultrasonic Tech
- KLA

**Module Producers and Integrators**
- Suniva
- Ampulse
- Intersil
- SemiSouth
- Solar Power Ind.
- Calisolar

**End-Users**
- FP&L / NextEra
- Lockheed Martin
- Progress Energy
- Austin Energy
- TSEC

*Must Expand Programs to Include the Diverse Supply Chain*
## What the U.S. cSi Industry Needs

<table>
<thead>
<tr>
<th>The challenge</th>
<th>The PVMC solution</th>
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<tbody>
<tr>
<td>Industry alignment</td>
<td>Roadmap and standards</td>
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<tr>
<td>Lack of infrastructure</td>
<td>Collaborate to fund and create it</td>
</tr>
<tr>
<td>Lack of place to work</td>
<td>Advanced manufacturing development facility</td>
</tr>
<tr>
<td>Metrology, test, and reliability</td>
<td>Develop, model, and share capabilities</td>
</tr>
<tr>
<td>Manufacturing cost – CIGS and cSi</td>
<td>Improved methods = reduced cost</td>
</tr>
<tr>
<td>Balance of system, technology, commercialization, workforce development</td>
<td>Support to the industry</td>
</tr>
<tr>
<td>Cost of PV energy to consumer</td>
<td>Consortium = shared knowledge and resources and reduced cost of manufacturing = reduced cost to consumer</td>
</tr>
</tbody>
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### PVMC cSi Manufacturing Development Facility is Essential
Expansion of PVMC-FL – Phase II

- Establish Next-gen RD&C Manufacturing Facility
  - 100,000 ft$^2$ site already available in Palm Bay, FL
  - Next-gen cSi wafer-to-module manufacturing-scale lines for Consortium Projects
  - Critical value-added element of PVMC for industry, houses consortium and member company projects.
Expansion of PVMC-FL – Phase II

- Establish Next-Gen RD&C Manufacturing Facility
  - 30 MW Cell and Module Manufacturing Line for Consortium Projects
  - Advanced and Next-gen tools sets

- Establish PV Commercialization Support Structure
  - Support transfers into manufacturing, provide incubation and start-up support

- Develop Training Workforce Development Programs
  - College, university, MDF, and member company programs

- National cSi Roadmap and Standards
  - Identify industry drivers, establish Executive Steering Committee/Working Groups

- Expansion of Consortium Programs (Next Slide)
PVMC-FL – Expansion Opportunity

- Build from existing PVMC-FL to expand program areas and increase member company value.

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<tr>
<td>Module</td>
<td>New Encapsulation Materials</td>
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<tr>
<td></td>
<td>Optimized cell connectivity in module</td>
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<tr>
<td></td>
<td>Smart Modules (integrated self-diagnostics, power electronics)</td>
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<tr>
<td></td>
<td>Easy Install Designs (weight, time)</td>
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<tr>
<td></td>
<td>Better Stringing/Tabbing Schemes</td>
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<tr>
<td>Feedstock/Wafering</td>
<td>Develop Incoming Wafer Specifications and In-line Metrology</td>
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<tr>
<td></td>
<td>Evaluate Siemens Process Alternatives</td>
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<tr>
<td></td>
<td>Lifetime Evolution - Correlate w/ Process History</td>
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<tr>
<td>Manuf. Productivity</td>
<td>Equipment Standardization (software, communication)</td>
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<tr>
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<td>Establish SPC and APC Systems for Improved Yield and Reliability</td>
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<tr>
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<td>Industry Benchmarking to Establish Manufacturing Best Practices</td>
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<td>Other</td>
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<td>PV Commercialization Support Structure / Incubation</td>
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Cross-cutting
Benefits to Florida

- Establish Florida as cSi Manufacturing Hub of the U.S.

- Brings manufacturing technical challenges to University researchers

- Establishes a magnet for industry, bringing companies to the Florida doorstep

“The SEMATECH Effect”
Value of Long Term Advanced Technology Partnerships

SEMATECH and New York

- Home to International SEMATECH HQ, the manufacturing arm of SEMATECH
- Attracted more than $3.2 billion dollars in capital investment for AMD microchip plant
- Created nearly 500 high-tech, high-wage immediately
- Supporting more than 500 companies across the state as key anchor of Albany Nanotech Initiative

SEMATECH and Texas

- Played a critical role in national security initiative
- Key driver of the launch of Texas as a leading high-tech economy
- Attracted more than $12 billion dollars in capital investment
- Created more than 80,000 high-tech, high-wage jobs in Texas
- Leader in government technology & economic development policy and investment

U.S. Scaled Estimates

Based on U.S. capturing same share of global market as Texas captured in U.S. market, annual economic impacts of:
- $482.8 billion in expenditures
- $235.4 billion in gross domestic product
- $141.8 billion in personal income
- $50.3 billion in supported retail sales
- More than 3.1 million permanent jobs

U.S. scaled estimates – more that 3.1 million permanent jobs

Semiconductor R&D has a multiplier effect of five (highest of all industries) resulting in an additional 400,000 ancillary jobs

[SEMATECH and the AMRC] will advance the technologies that will help drive our state’s economy for the next 50 years.

Texas Governor
Rick Perry
AMRC Launch

“[SEMATECH North is] the most exciting development since the construction of the Erie Canal.”

New York Governor
George Pataki
SEMATECH North ribbon cutting, 2003
A little humor to end with…
Thank you for your attention !!!
Photovoltaic Industry Overview

- Why is solar energy and PVMC important?
  - Quality of life/environment - most abundant renewable energy source
    - Plentiful energy for the planet while preserving natural resources/ecosystem
    - Potential scale/availability of solar energy
    - Potential uses of solar PV technology
  - Economic – market potential, contribution to economic growth, job creation
    - Solar energy will soon develop into one of the world’s largest industries - generating billions of dollars of revenue, and creating millions of high paying jobs
  - National – opportunity for US leadership in technology innovation and manufacturing
    - The clean energy race is well underway - energy technologies not only need to be invented in America, but also manufactured in America

- What are the challenges for the solar market?
  - Levelized Cost of Electricity (LCOE), $/kWh
    - System cost, system efficiency, system reliability
  - Business challenges
    - Bankability, etc
  - National/Regional challenges
    - Funding needed to establish the foundation and catalyst
    - Weak and declining manufacturing market share
    - Industry alignment