High-Rate Fabrication of a-Si-Based Thin-Film Solar Cells Using Large Area VHF PECVD Processes

Principle Investigator:

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Photovoltaics – Long Term

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Project Overview

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Timeline

- Project start date: 7/1/08
- Project end date: 6/30/11
- Percent complete: 80%

Barriers

- Barriers addressed:

  Thin film solar cell modules
  - Material utilization & cost
  - Manufacturing processes
  - Efficiency

Budget

- Total project funding

  DOE share: $1,442,266

  Contractor share: $418,730
- Funding received in FY09: $477,732
- Funding for FY10: $488,644

Partners

- Collaboration: Xunlight Corp.
- Project lead: Univ. Toledo

Project Organization

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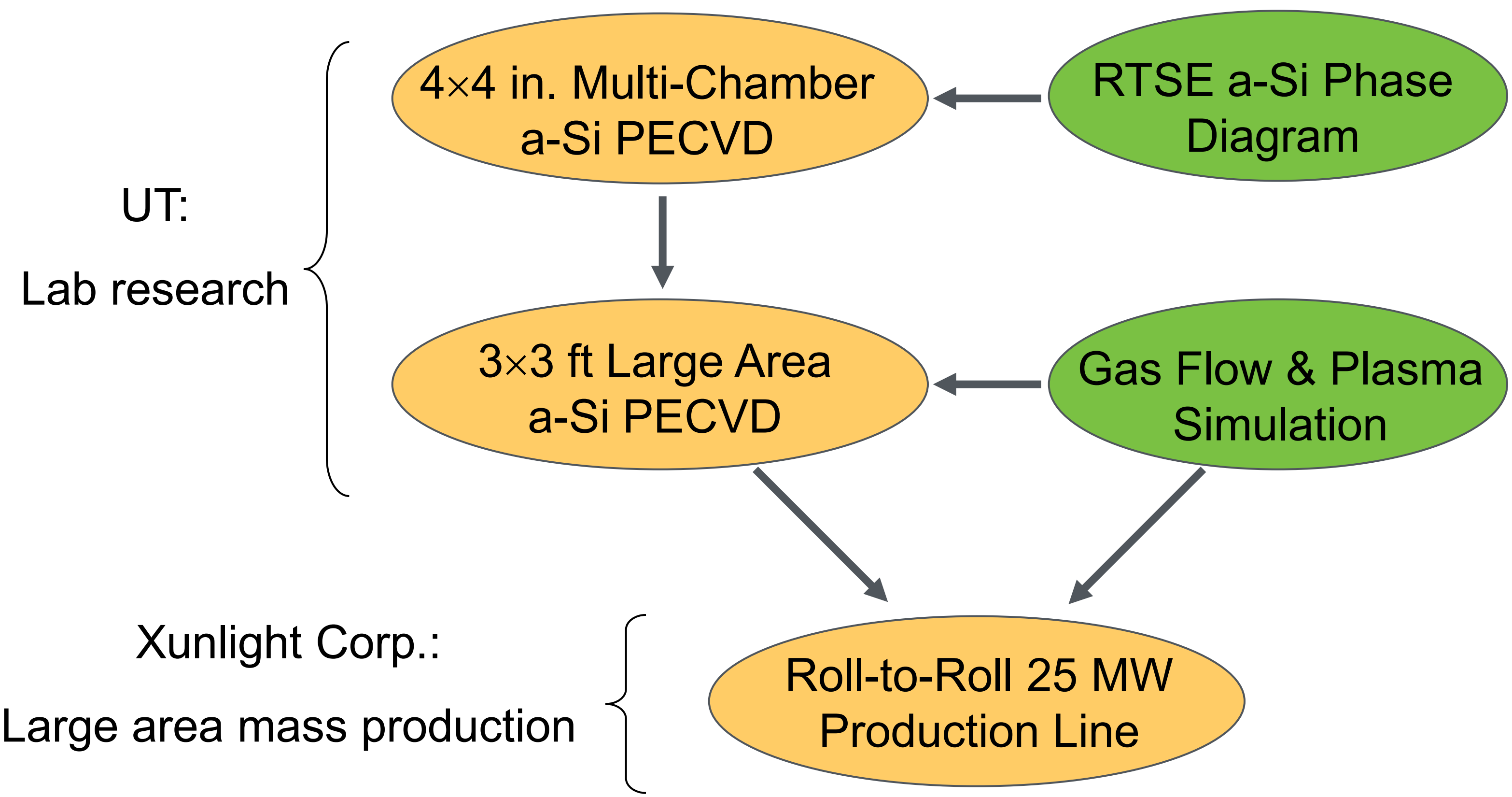
- Professors and Research Professors (UT): 5
- Post-doctors/PhD Students (UT): 5
- Research Scientists (PhD) (Xunlight): 4
- Research Assistants/Engineers (UT/Xunlight): 6



Project Challenges

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- **Challenges for a-Si based thin film solar cells in large area process**

  - *Low deposition rates.*

    2~3 Å/s a-Si, 1 Å/s a-SiGe in order to achieve stable device performance (~10% degradation). A higher deposition rate leads to large degradation (~20%).

  - *Large area uniformity at high deposition rates.*

    RF – better uniformity, but film quality and rates need improvement.

    VHF – better film quality and higher rates, problems with large area uniformity.

  - *High efficiency and stable performance a-Si cells with simple device structure*.

- **Ultimate goals**

  - Develop technologies suitable for mass production of a-Si based thin film solar panels at low costs in terms of materials, processes, and equipment.

  - Maintain a leadership position of the USA in thin film PV manufacturing.

Project Objectives

- **General objectives and goals of the present project:**

  - Develope a technology for high rate fabrication of 8 Å/s a-Si, and 20 Å/s nc-Si or >4 Å/s a-SiGe absorber layers suitable for large area process.

  - Achieve 10% stable efficiency a-Si/nc-Si or a-Si/a-SiGe tandem-junction solar cells in large area (3 ft×3 ft) process.

- **Project goals over the past year (May 09 - April 10):**

  - Demonstrate large area (3ft×3ft) high rate deposition of ≥8 Å/s a-Si with thickness non-uniformity <± 10% - **GO/NO-GO DECISION**.

  - Demonstrate large area (3ft×3ft) high rate deposition of ≥4 Å/s a-SiGe or ≥20 Å/s nc-Si with thickness non-uniformity <±10%.

  - Achieve Eff ≥7.0% for a-Si:H, and a-SiGe or nc-Si:H single-junction cells deposited at the high rates.

General Approach to Final Goals

- **High rate process of a-Si/a-SiGe or a-Si/nc-Si tandem cells with superior stability and high efficiency.**

- **Comparison of a-Si/a-SiGe & a-Si/nc-Si tandem cells:**

Absorber layer thickness & deposition rates

- a-Si/a-SiGe – 250 nm/300 nm (8 Å/s, 4 Å/s) – a-SiGe 2.4X longer.

- a-Si/nc-Si – 250 nm/2500 nm (8 Å/s, 20 Å/s) – nc-Si 4X longer.

- nc-Si deposition is still 1.6X longer than a-SiGe at the target high rates.

PECVD process compatibility

- a-Si & a-SiGe – similar process parameters: temperature, pressure, power source and density, deposition rates.

- a-Si & nc-Si – process parameters are quite different.

Stability of a-SiGe & nc-Si

- Conventional PECVD a-SiGe >20% degradation vs. nc-Si ~10% degradation.

Technical Approach Summary

- Stable a-Si top cells deposited at high rates (8 Å/s) near the phase transition edge of a-Si/nc-Si.
- High efficiency and stable a-SiGe bottom cells deposited near depletion mode at high rates (4~8 Å/s) with graded Ge profile.
- VHF deposition of nc-Si at high rates (10~20 Å/s).
- High performance a-Si/a-SiGe tandem cells (>10% stable efficiency) deposited at high rates.
- PECVD cathode improvement for large area uniformity (±10%).
- Simulation of large area gas flow for optimization of a-Si uniformity.
- RTSE phase diagram for achieving optimized process of a-Si & a-SiGe absorber layers deposited at high rates.
- Transfer UT lab research to Xunlight Corp. for large area roll-to-roll mass production of high efficiency a-Si based thin film solar panel.

Accomplishments In Previous Year

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7/2008~4/2009

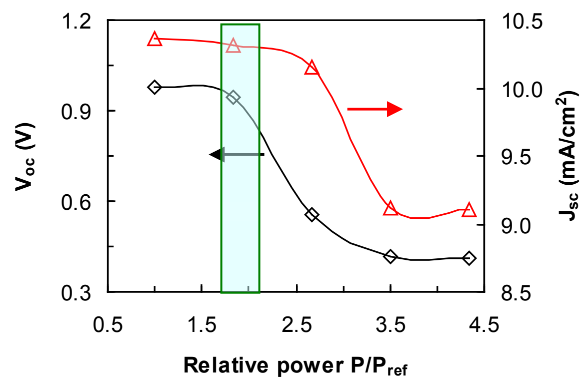
- Advanced modeling of gas flow and plasma discharge
  - Established the baseline for large area gas flow and plasma simulation.
- Large area PECVD system
  - Improved the large area cathodes and gas delivery system.
- Large area high rate deposition of a-Si based solar cells
  - Deposition rate was improved from 1~2 to 5~8 Å/sec.
  - Initial efficiency reached >8% for single junction cells .
- RTSE Si deposition phase diagrams
  - Installed the RTSE system in PECVD process chamber.
  - Demonstrated the operation of the RTSE system in the PECVD system.

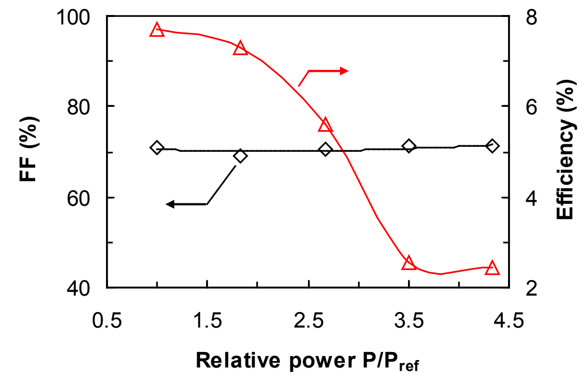
Accomplishments – a-Si Top Cell

5/2009~4/2010

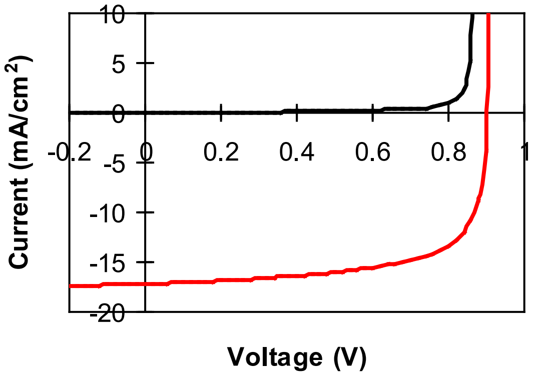
- **Achieved high rate deposition of a-Si (8 Å/s) under high power near depletion mode. The a-Si top cells exhibit excellent stability – Eff=9.19%**
- **Reaching project goals: 8 Å/s, Eff> 7%.**

Example of I-V performances and stability of a-Si solar cell deposited near depletion mode at ~8 Å/s.



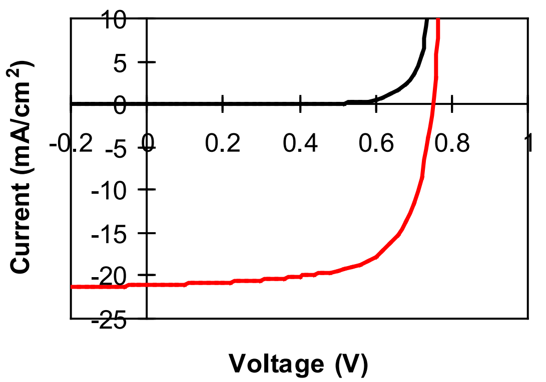


Solar cell: a-Si top cell	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Initial	0.842	17.216	71.04	10.298
Stable	0.905	16.518	61.47	9.194
Degradation (%)	-7.48	4.05	13.47	10.72



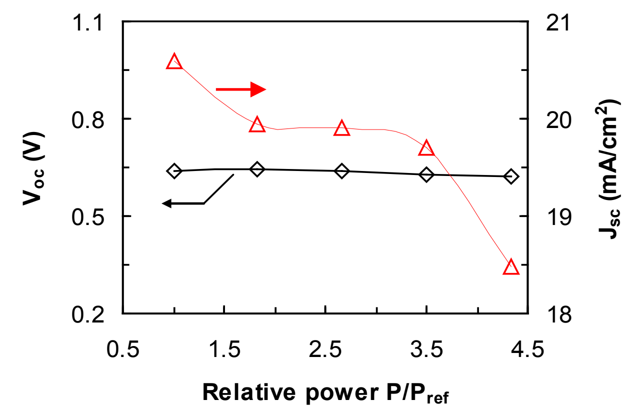
Accomplishments – a-SiGe Cell

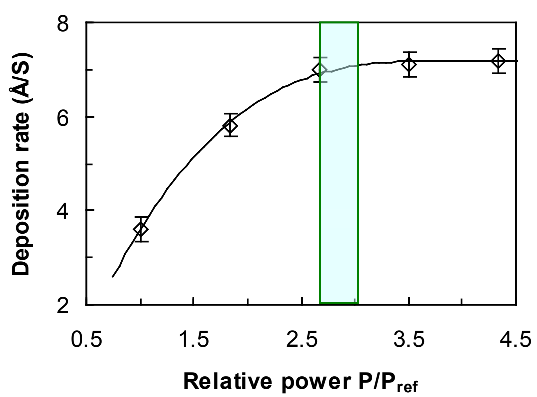
- **Achieved high rate deposition of a-SiGe (4~7 Å/s). With graded Ge profile, the a-SiGe bottom cells exhibit excellent performances.**
- **Reaching project goals: 4 Å/s, Eff> 7%.**

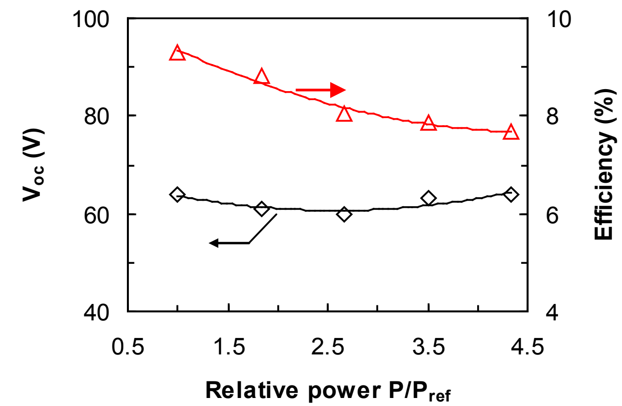


V_{oc}=0.751 V
J_{sc}=19.71 mA/cm^2 (QE)
FF=67.28%
Eff=9.96%

I-V Performances of a-SiGe solar cell deposited near depletion mode at high rates 4~7 Å/s.







- **VHF deposition of nc-Si at rates >20 Å/s – reaching project goal**

Si_2H_6/H_2 ratio	J_{sc} (mA/cm^2)	V_{oc} (V)	*FF*	Effi. (%)	$J_{sc\text{-}red}$ (mA/cm^2)	r_d (Å/s)
2.25/100	20.94	0.504	0.712	7.5	9.56	32.5
2.25/200	20.74	0.512	0.716	7.6	8.40	32.8
2.25/300	21.59	0.505	0.736	8.0	9.82	30.4

- Deposition rate reached 20 Å/s goal. However, this rate is still not enough for Xunlight Corp. mass production.
- Increasing the deposition rate leads to unacceptable uniformity.

Accomplishments – a-Si/a-SiGe

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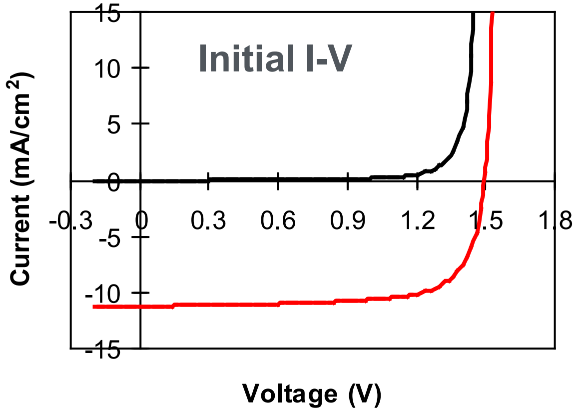
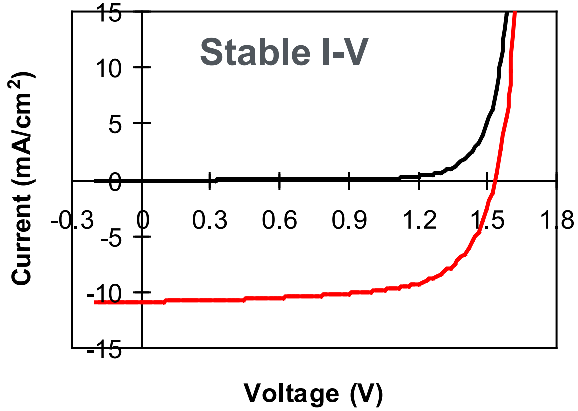
- **Achieved high efficiency a-Si/a-SiGe tandem cells deposited at high rates (a-Si 8 Å/s, a-SiGe 4 Å/s) with <10% degradation – similar to nc-Si stability.**
- **The stabilized efficiency reached 11.108%, exceeding the project goal of 10%.**

Solar cell: a-Si top cell	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff (%)
Initial	1.496	11.229	73.28	12.313
Stable	1.533	10.879	66.60	11.108
Degradation (%)	-2.47	3.12	9.12	9.79





Accomplishments – RTSE Study

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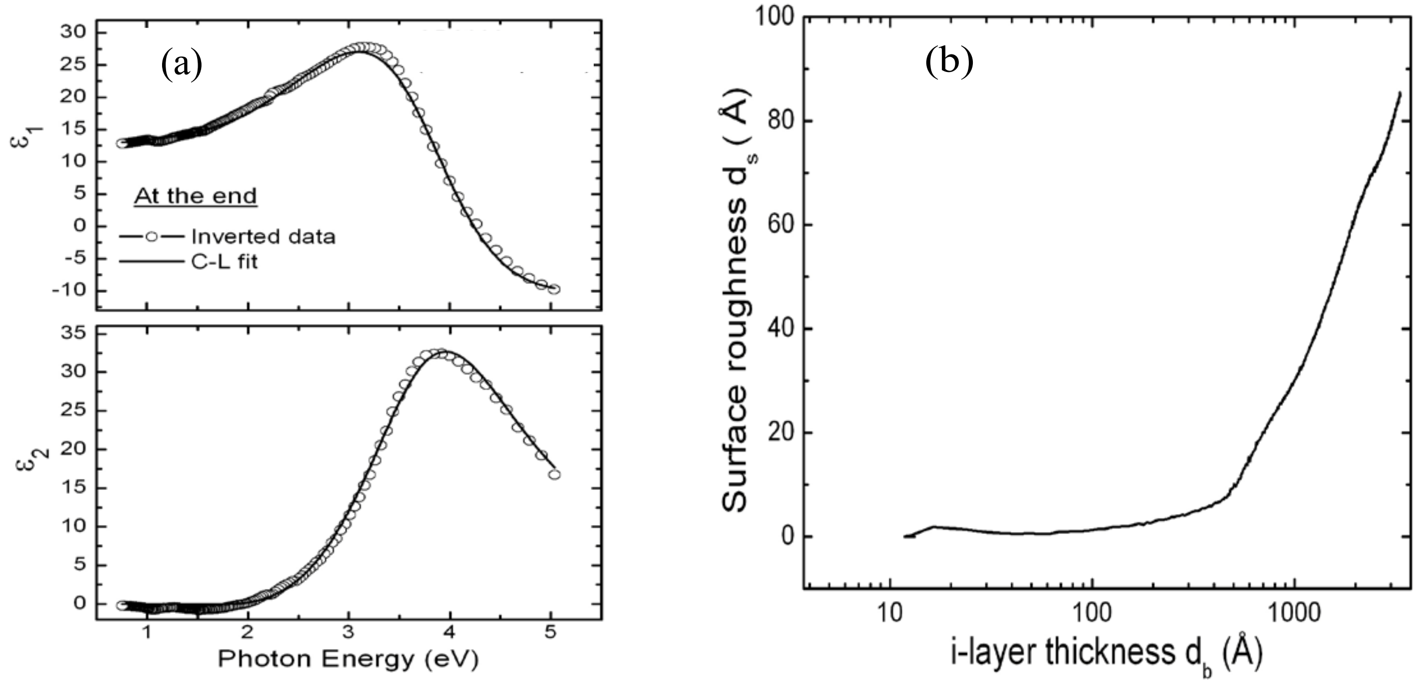
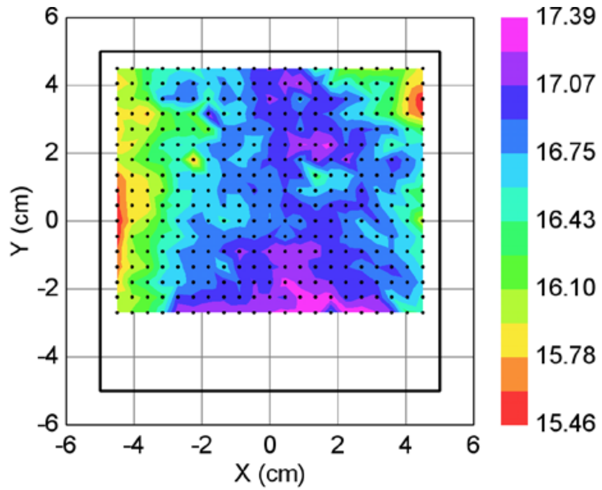
- **Real time spectroscopy ellipsometry (RTSE) study of a-Si layers deposited at high rates helps control the microstructures and properties of the a-Si films, which is the key towards high performance a-Si/a-SiGe solar cells.**



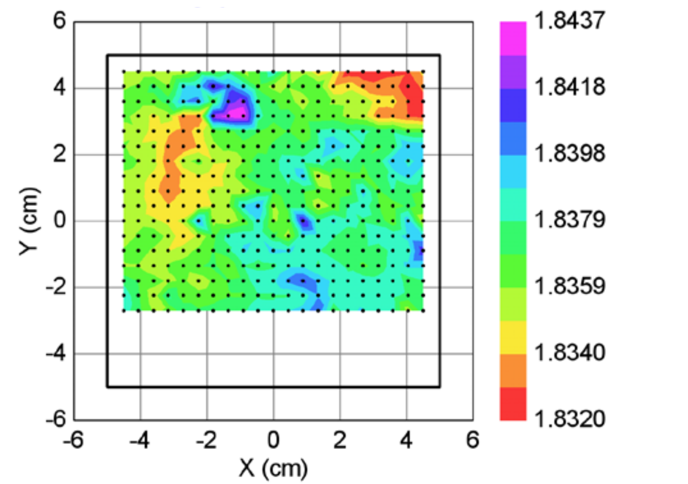
(a) Dielectric function near the end of the deposition and (b) the surface roughness versus bulk layer thickness on a logarithmic-linear plot

Accomplishments – RTSE Study

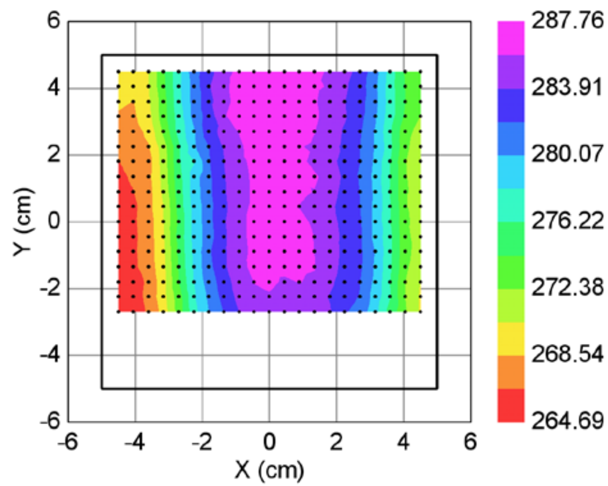
SE mapping of individual layers in Ag/ZnO/n-i-p/ITO cell structure



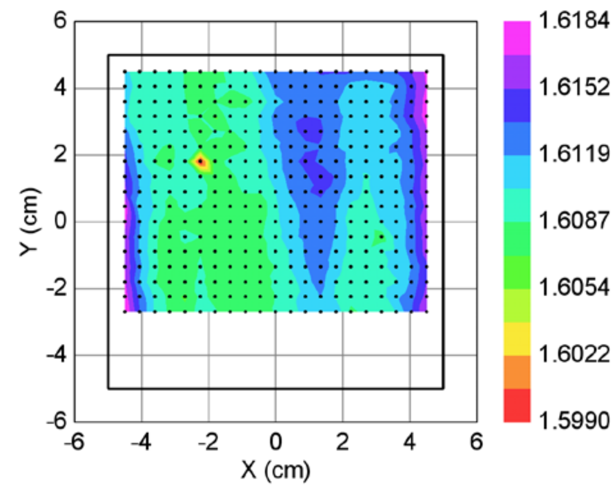
p-layer thickness: 164 ± 10 Å



p-layer band gap: 1.838 ± 0.006 eV



i-layer thickness: 2760 ± 120 Å

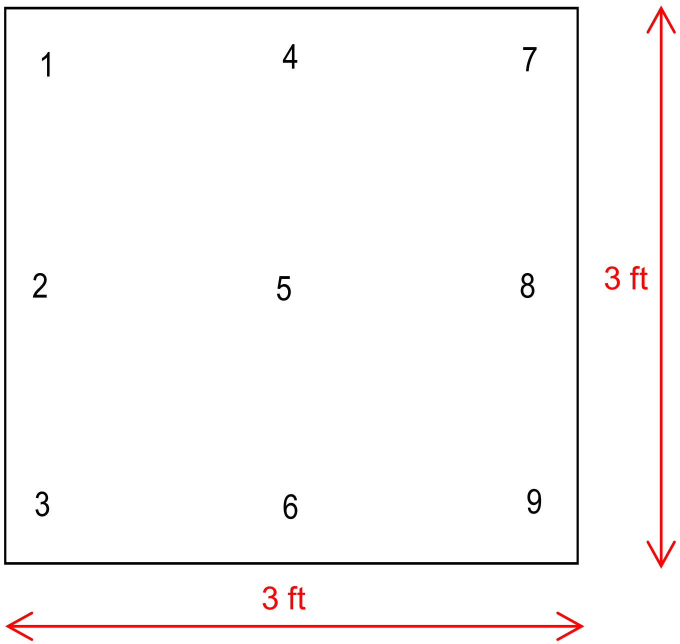


i-layer band gap: 1.61 ± 0.01 eV

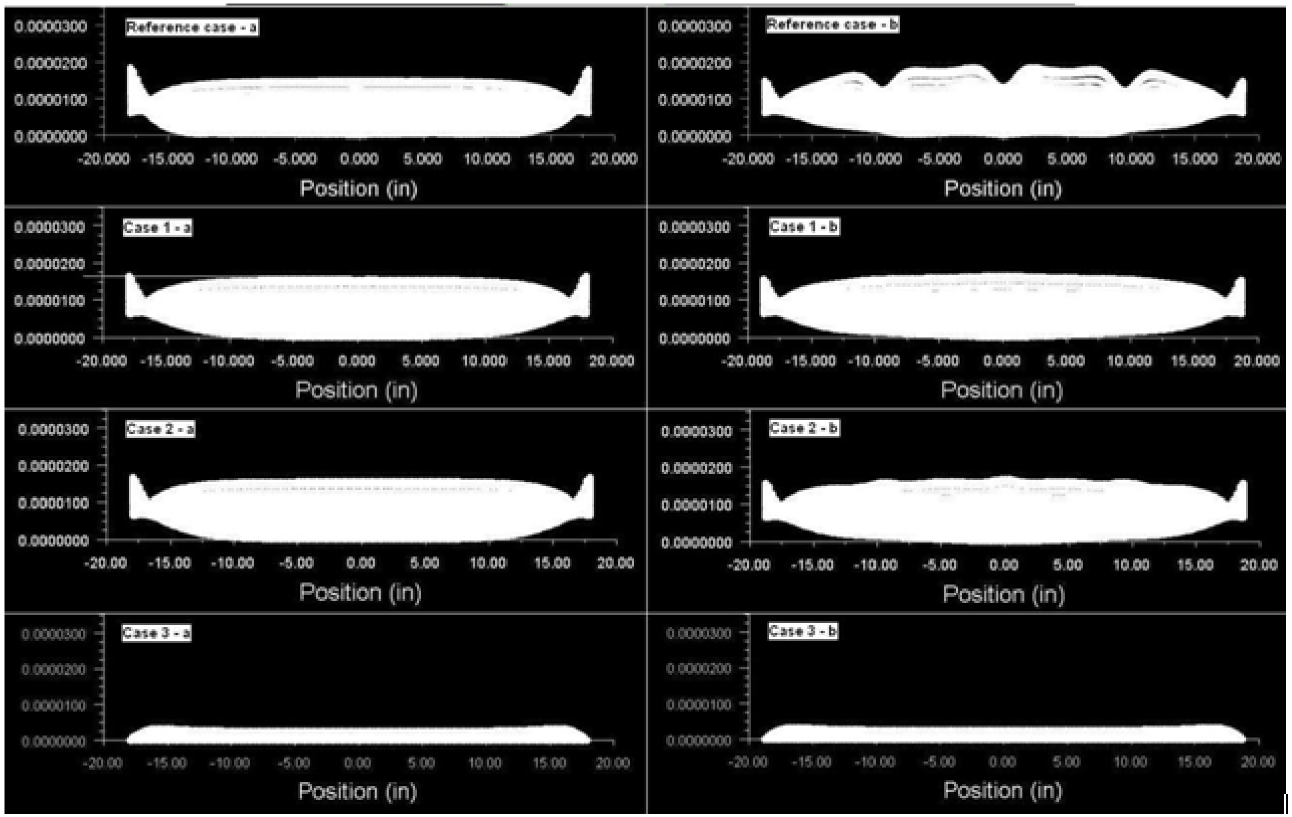
Accomplishments – Uniformity

- **At high deposition rates >8 Å/s, achieved ±10% a-Si film uniformity over 3ft x 3ft large area by improving the PECVD cathode design.**
- **Reached the project goal for 2nd year GO/NO-GO DECISION.**

3mw 332	thickness	Error
Location	nm	(%)
1	380	8.1
2	345	-1.9
3	347	-1.3
4	373	6.1
5	331	-5.9
6	350	-0.5
7	365	3.8
8	314	-10.7
9	360	2.4
Total	3165	
average	351.67	



- **Simulation of large area gas flow helps obtain an optimized gas distribution.**
- **Meet project milestone.**



Variation of gas velocity (m/sec) on vertical axis, versus position on horizontal axis, on the plane of interest adjacent to the substrate.

Future Plans (FY 2011 and beyond)

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- **Transfer the high rate technology to Xunlight Corp. for mass production. Demonstrate high efficiency a-Si based thin film solar cells over 1 m wide and 100 m long substrate.**

- **Further increase the large area uniformity of a-Si and a-SiGe to ±5% by improving the plasma discharge uniformity.**

- **Further improve the deposition rate for a-SiGe to 6~8 Å/s to reduce the cost of mass production PECVD system. Maintain the stability of high rate deposited a-SiGe that is suitable for high efficiency a-Si/a-SiGe tandem applications – exceeding project goals.**

- **Further improve the performance of a-Si/a-SiGe tandem cells deposited at ~8 Å/s rates – exceeding the project goal of 10% stable efficiency.**

- **Explore low cost back reflectors, such as Al/ZnO, for replacing the expensive Ag/ZnO, while reaching the 10% efficiency goal of the project.**

Summary

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- **Near depletion mode, high rate deposition of 8 Å/s a-Si and 4~7 Å/s a-SiGe can be achieved. The a-Si and a-SiGe solar cells exhibit excellent stability with efficiencies exceeding the project goal of 7%.**

- **The stabilized efficiency of the high rate deposited the a-Si/a-SiGe tandem cells reaches 11.1%, exceeding the project final goal of 10%.**

- **The high rate deposited a-Si/a-SiGe tandem junction cells exhibit less than10% degradation, which is in the same range of a-Si/nc-Si cells. The cost saving for a-Si/a-SiGe process is significant in mass production in terms of the process system and materials.**

- **Real time spectroscopy elliposometry is a useful tool in controlling the microstructure of high rate deposited a-Si films.**

- **Computer simulation of gas flow helps optimize the large area PECVD cathode to reach the uniformity goal of ±10%.**

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End of Presentation

Thank You!

The University of Toledo PI: Dr. Xunming Deng

5/24~27/2010 Washington, DC