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Critical Research for Cost-effective Photoelectrochemical Production of Hydrogen

Liwei Xu

Midwest Optoelectronics, LLC

Toledo, Ohio

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Project ID # PDP 34

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Overview

Timeline

- Project start date: 10/13/2004
- Project end date: 10/12/2007
- Percent complete: 30%

Budget

- Total project funding
  - DOE share: $2,921,501
  - Contractor share: $760,492
- Funding received in FY05: $100,000
- Funding received in FY06: $200,000
- Funding for FY07: $400,000, $200,000 for NREL

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Barriers Addressed and Partners

Barriers addressed

- DOE MYPP Objective for PEC
  - By 2015, demonstrate direct PEC water splitting with a plant-gate hydrogen production cost of $5/kg projected to commercial scale.
- Technical Targets:
  - 2010: STH Eff > 9%; Durability >10,000 hours; Cost < $22/kg
  - 2015: STH Eff > 14%; Durability >20,000 hours; Cost < $5/kg
- PEC Hydrogen Generation Barriers -- MYPP 3.1.4.2.3
  - M. Materials Durability
  - N. Materials and Systems Engineering
  - O. PEC efficiency

Partners

University of Toledo	Dr. Xunming Deng
National Renewable Energy Laboratory	Dr. John Turner
United Solar Ovonic Corp.	Dr. Jeff Yang

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Objectives

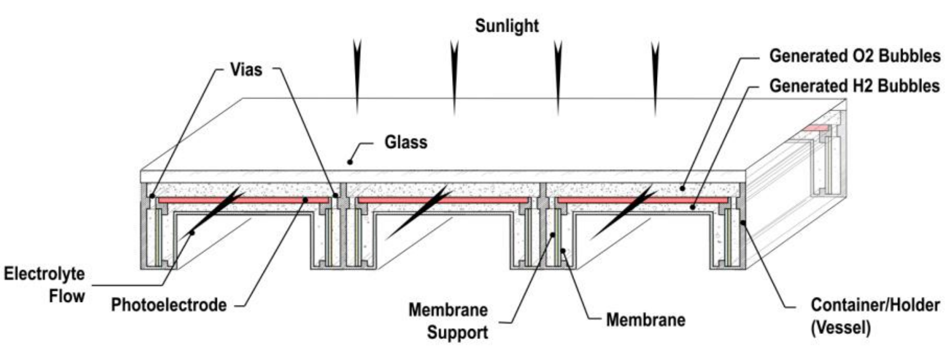
- To develop critical technologies required for cost-effective production of hydrogen from sunlight and water using thin film-Si based photoelectrodes.

- To develop and demonstrate, at the end of the 3-year program, tf-Si based PEC systems with 9% solar-to-hydrogen efficiency with a lifetime of 10,000 hours and with a potential hydrogen cost below $22/kg.

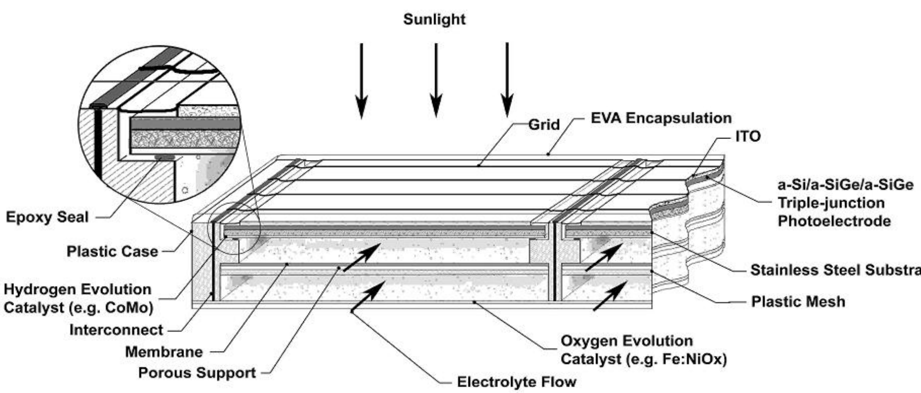
Approaches

Two approaches are taken for the development of efficient and durable photoelectrochemical cells.

An immersion-type PEC cells



A substrate-type PEC cell



Research Tasks

- Task 1: Transparent, conducting and corrosion resistant coating for triple-junction tf-Si based photoelectrode
- Task 2: Hybrid multijunction PEC electrode having semiconductor-electrolyte junction
- Task 3: Understanding and characterization of photoelectrochemistry
- Task 4: Fabrication of low-cost, durable and efficient immersion-type PEC cells and systems
- Task 5: Fabrication of large-area, substrate-type PEC panels

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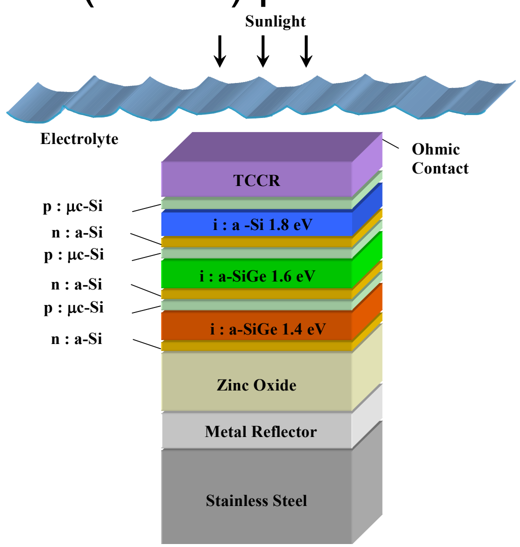
Approaches for PEC electrodes

Two separate approaches for the development of high-efficiency and stable PEC photoelectrode for the immersion-type PEC cells:

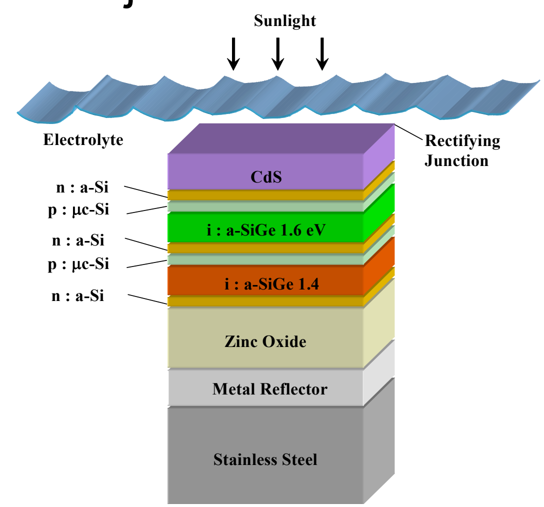
Approach 1A (Task 1):

- Develop triple junction tf-Si photoelectrodes covered with a transparent, conductive, and corrosion resistant (TCCR) protection layer



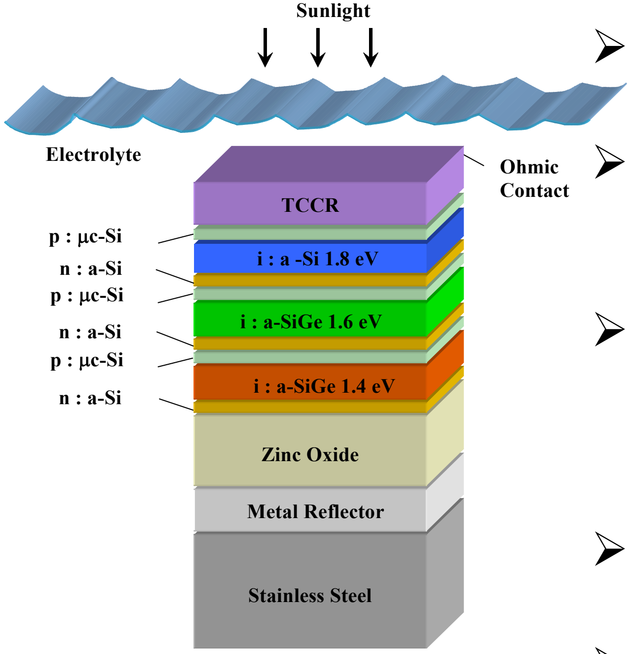
Approach 1B (Task 2):

- Develop hybrid, triple junction photoelectrodes with a semiconductor-electrolyte junction as the top junction and tf-Si alloys as the middle and bottom junctions



Task 1: TCCR Layer for Triple-Junction tf-Si Photoelectrode

A triple-junction tf-Si based solar cells (a-Si/a-SiGe/a-SiGe or a-Si/a-SiGe/nc-Si) are used to generate the voltage bias and a transparent, conducting and corrosion resistant (TCCR) coating is deposited on top to protect the semiconductor layer from corrosion while forming an ohmic contact with the electrolyte



Materials and Process Requirement for TCCR

- High transmission – to allow photons reach the solar cells
- High conductivity – to allow electron transfer to/from electrolyte
- High chemical and electrochemical stability – to protect the solar cell from being corroded
- Low cost – to reduce the overall system cost
- Low temperate deposition (below 250 °C) – so that the a-Si layers deposited earlier would not degrade.

Major Activities under Task 1

- Fabrication of triple-junction a-Si/a-SiGe/a-SiGe solar cells (Photoelectrodes)
- Fabrication of triple-junction a-Si/a-SiGe/nc-Si solar cells (Photoelectrodes)
- Deposition of transparent, conducting and corrosion-resistant coating using sputtering
- Optimization of a sputter system with four linear targets (4”x15”), capable of making TCCR films on 1ft x 4ft substrates.

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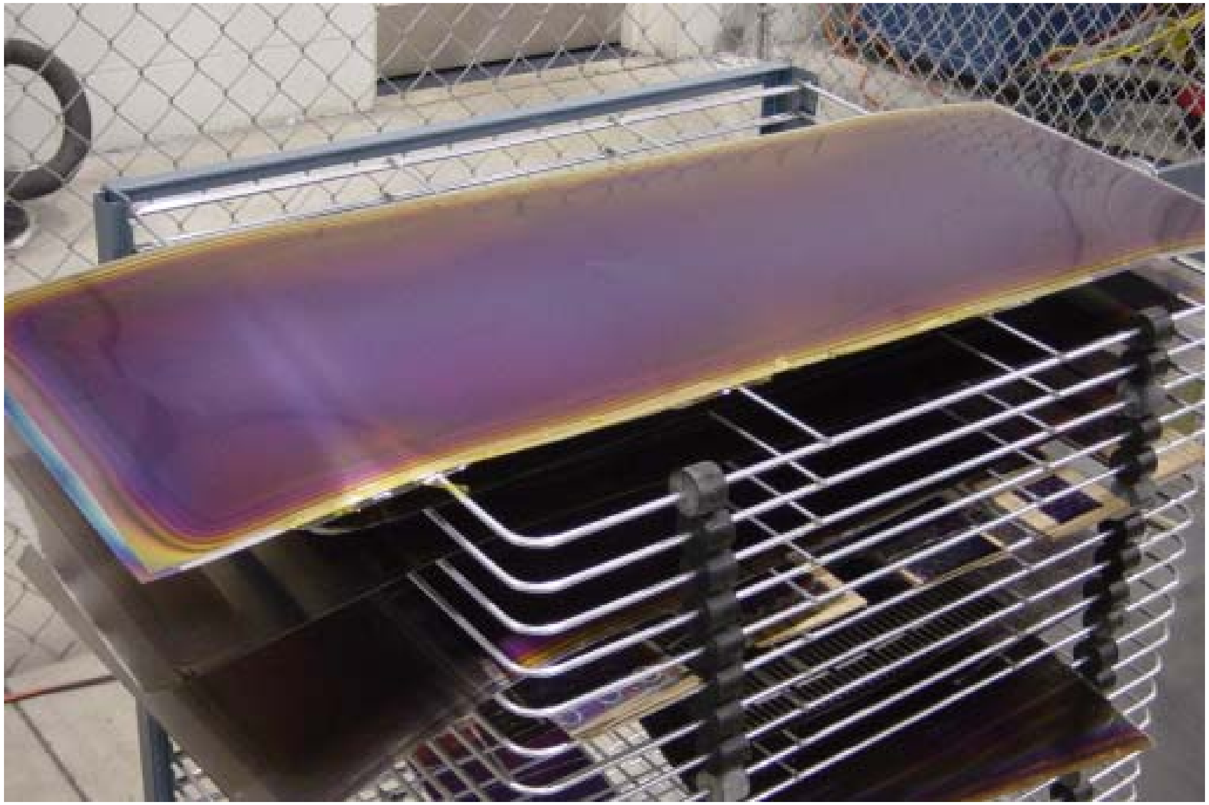
Optimization of large-area sputter system



Optimization of a sputter system with four linear sputter guns to make TCCR layer on 1ft x 4ft substrates. Shown in the right photo are substrates coated with Indium Tin Oxide.

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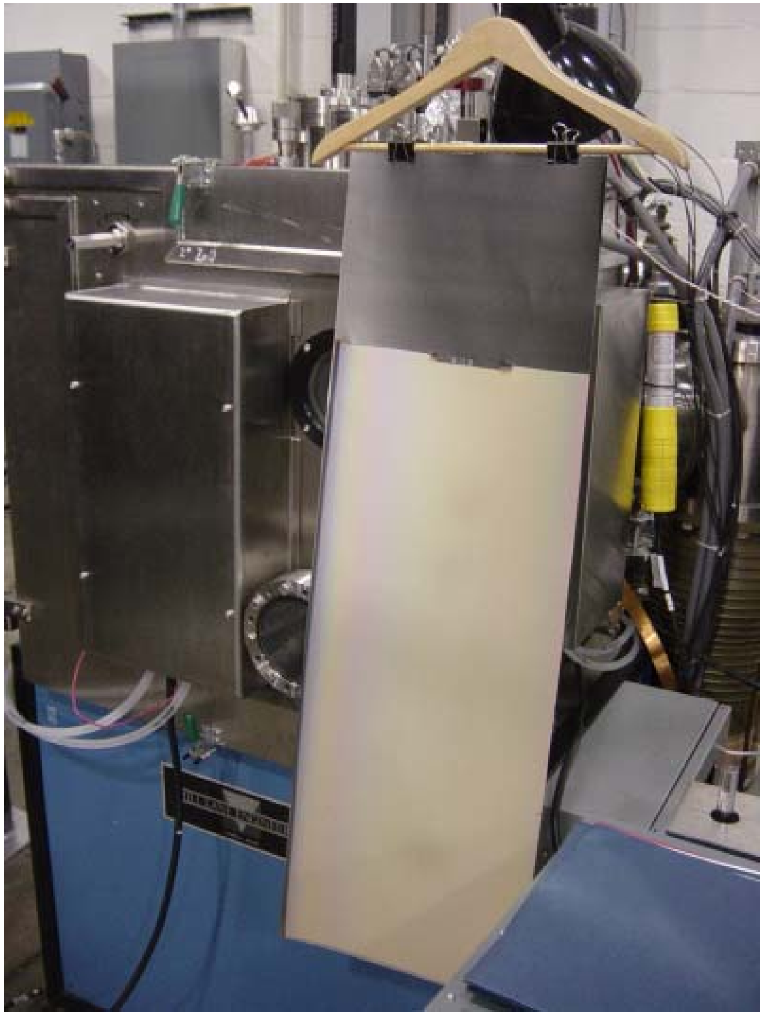
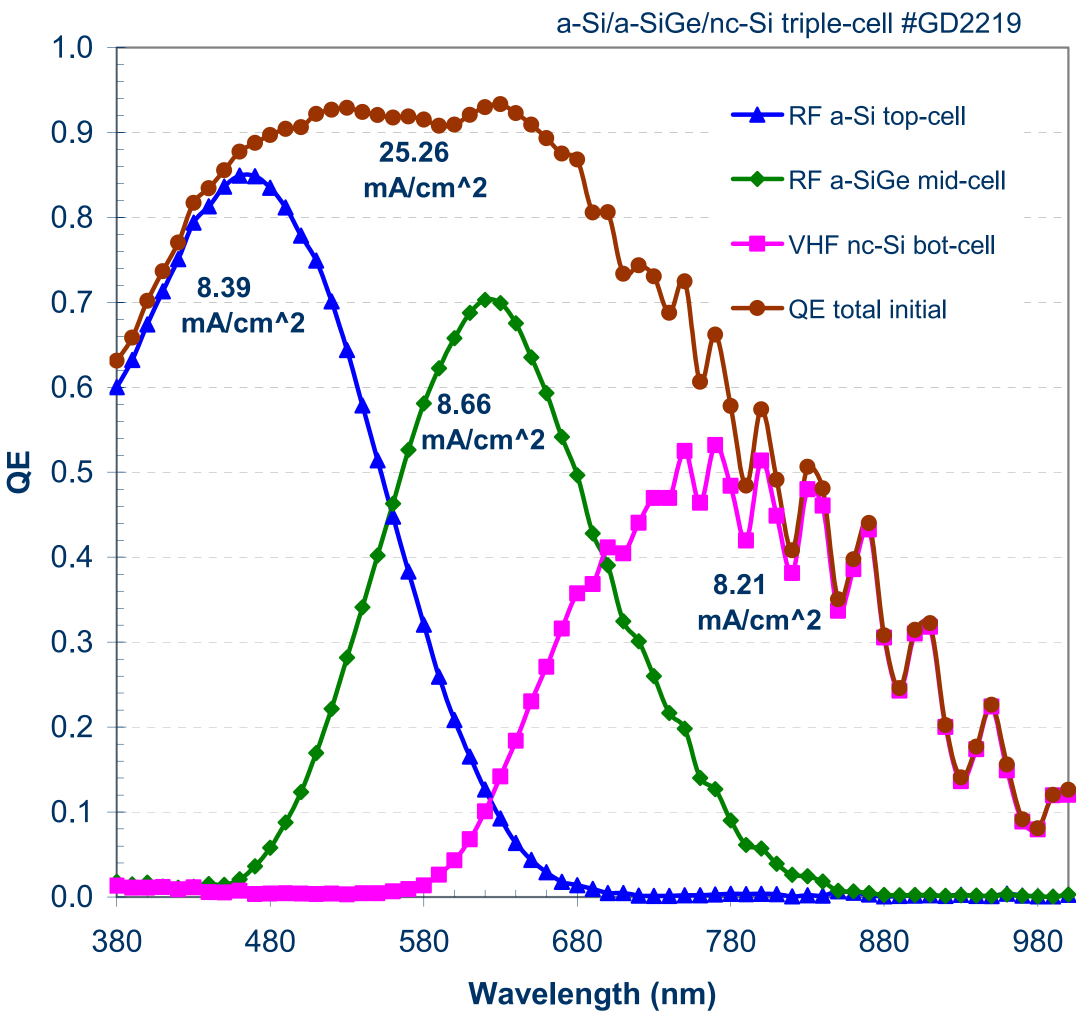
Large-Area Sputter System

Large-area 4-gun sputter system for coating of oxide films. Shown in the right photo is zinc oxide coated on stainless steel.



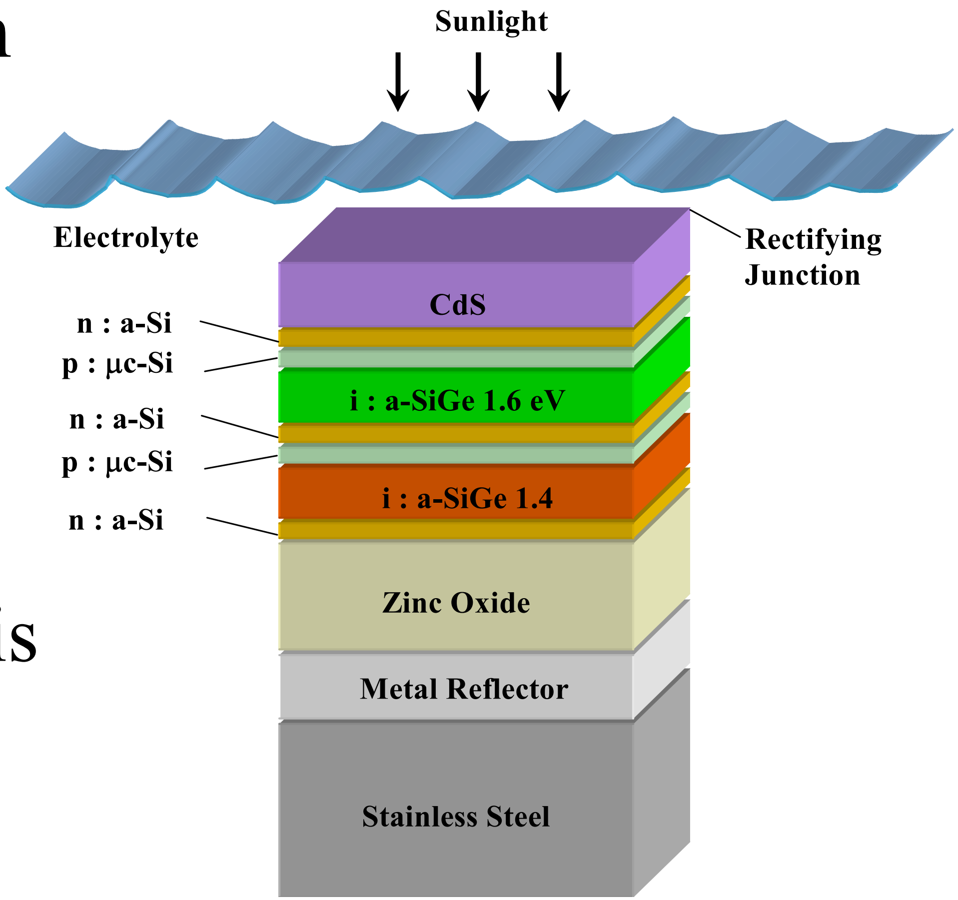
Triple-junction Photoelectrodes



Quantum efficiency curves of improved triple-junction a-Si/a-SiGe/nc-Si photoelectrodes

Task 2: Hybrid PEC Photoelectrodes

A hybrid structure in which two tf-Si based junctions (middle and bottom junctions of the present triple-junction tf-Si cell) provide a voltage bias (around 1.1V) and a third junction (the top junction) is a rectifying junction between a photo-active semiconductor (PAS) and the electrolyte.



Major Activities under Task 2

- Fabrication of double-junction a-SiGe/a-SiGe solar cells (photoelectrode)
- Fabrication of double-junction a-SiGe/nc-Si solar cells (photoelectrode)
- Deposition of photoactive semiconductor layer for semiconductor-electrolyte junction
- Construction of large-area sputter system to make photoactive semiconductor layers in large area

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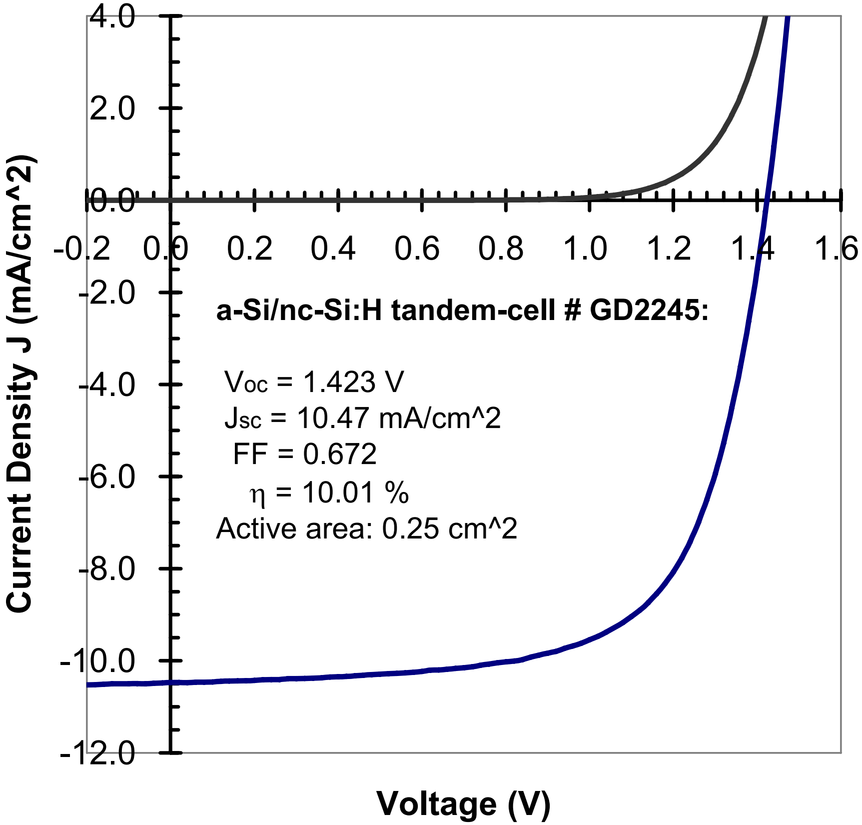
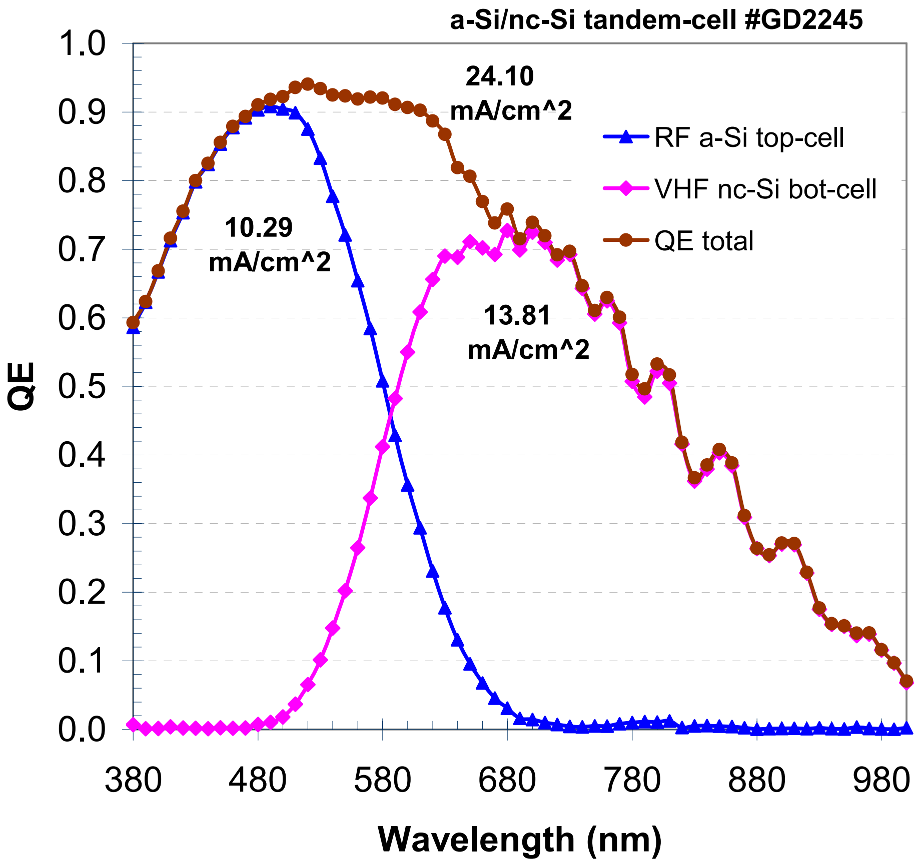
10% a-Si/nc-Si tandem-junction solar cell





- η = 10.01% initial efficiency (V_{oc} = 1.423V, J_{sc} = 10.47 mA/cm^2, FF = 0.672) was achieved for a-Si/nc-Si tandem-junction solar cells on UT-BR substrate with SS/Al/Ag/ZnO structure.

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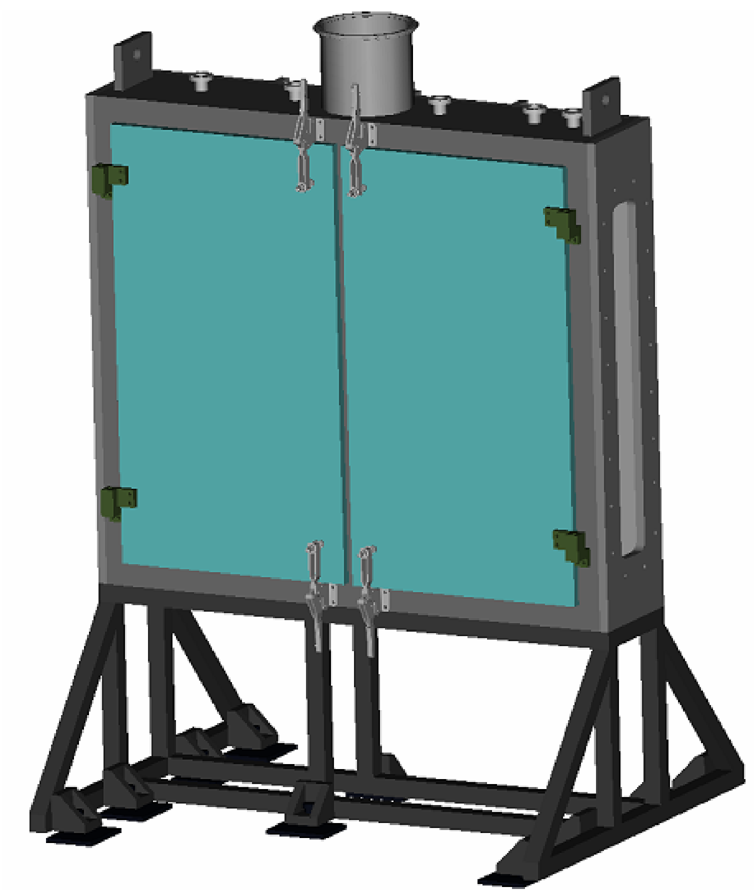
Large-area sputter system



- Designed a large area sputter system capable of making photoactive semiconductor layers on 3 ft x 3ft substrates.
- System has already been custom made by outside vendor according to MWOE supplied engineering drawings.
- System can be used to make oxides and metal layers for PEC electrodes.

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Task 3: Understanding and Characterizing PEC

- Several efforts are on going under this Task.
- NREL team is currently developing improved understanding of PEC process for a-Si based photoelectrodes.
- An outdoor solar testing facility has been installed and used for outdoor testing of PEC panels
- Large-area IV tester has been purchased.
- Large-area environmental chamber has been installed and used to test long-term durability and failing mechanism for PV and PEC panels.

MWOE Outdoor Solar Testing Facility

MWOE's outdoor solar testing facility for testing PEC hydrogen production

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Large-Area I-V Tester Purchased

Keithley 2420 Sourcemeter Voltage/Current source and measuring unit for obtaining computerized current-voltage characteristics of larger area PEC panels.

Spire 4600 Series large area solar simulator, purchased using cost-share funds, will allow accurate characterization of the active component of large-area PEC panels up to 200 cm x 137 cm (6.5' x 4.5') in size.

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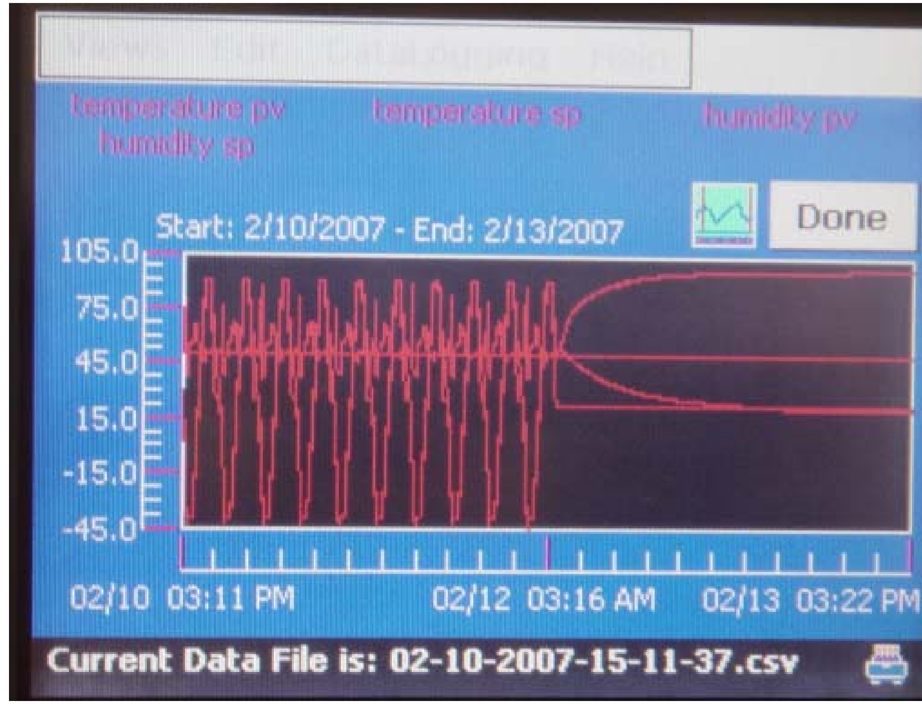
Environmental Test Chamber Installed



Screenshot of environment chamber controller, showing multiple temperature cycles between minus 40 and +90 degrees Celsius.

(Temperature on vertical axis.)

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Task 4: Immersion-type PEC cell

- Focus on Task 4 is on the construction and optimization of deposition system that will be used for making large-area photoelectrode for immersion-type PEC cells
- Designed and constructed a system capable of making 1ft x 3ft photoelectrodes
- Improved deposition uniformity over large area
- Continued the design and optimization of immersion-type PEC cells

New System for Depositing Photoelectrodes

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1ft x 3ft a-Si photoelectrodes from new PECVD system

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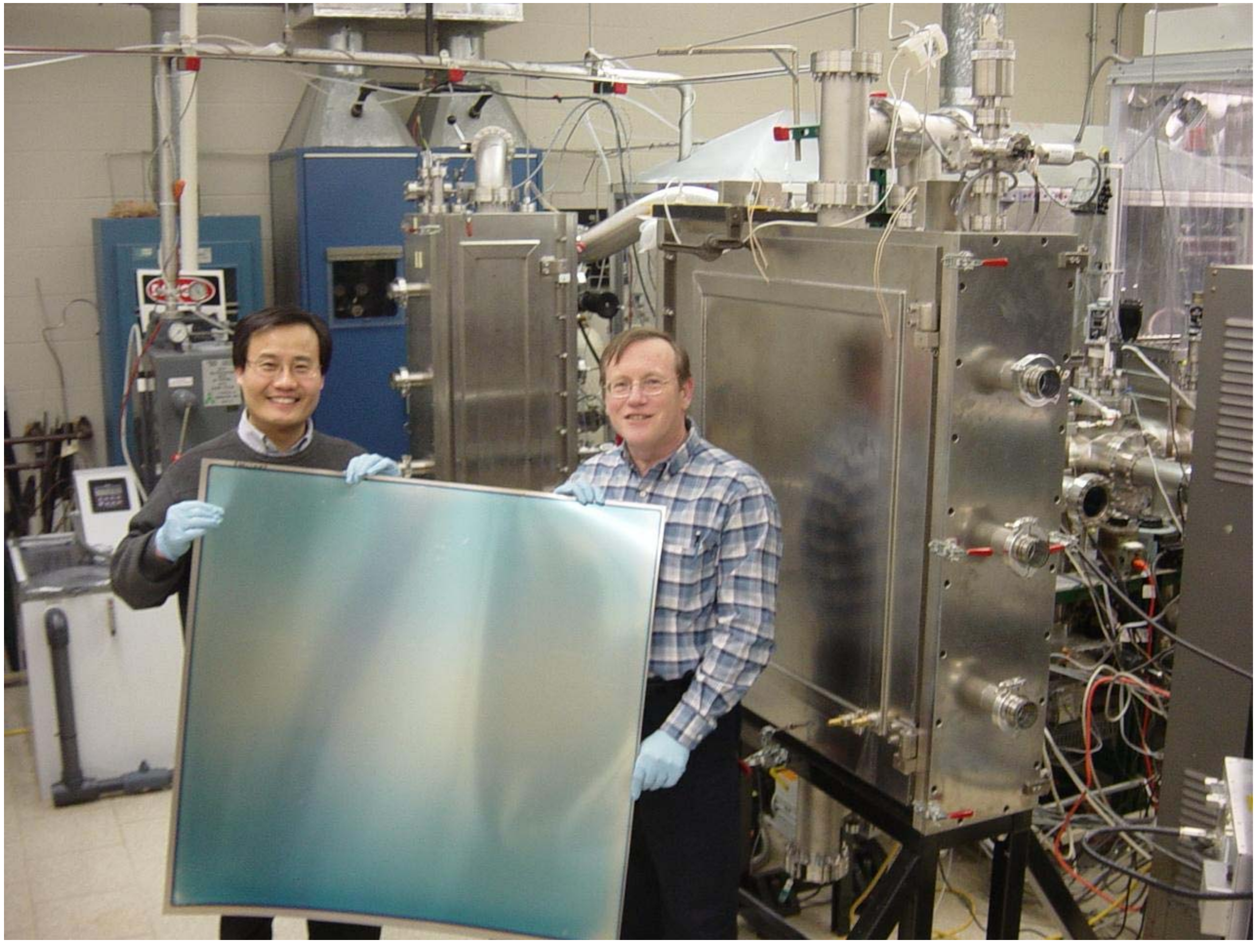
New System for Depositing Photoelectrodes



A second new PECVD system, capable of making 3 ft x 3ft photoelectrodes have been designed and constructed. Amorphous Si photoelectrodes (solar cells) have been fabricated in this new system.

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Task 5: Fabrication of Substrate-Type PEC cells

- Focus under this task has been on establishing facilities to make substrate-type PEC cells in large area.
- Designed and built a computer-controlled process for application of current-conducting grids in the substrate-type PEC cells
- Designed and built a fabrication facility for making substrate-type PEC electrodes.
- Designed, developed and constructed a photo-assisted electrochemical shunt passivation system to remove shunts and shorts in the photoelectrodes.

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Newly Developed Fabrication Facility for Substrate-type PEC Electrodes

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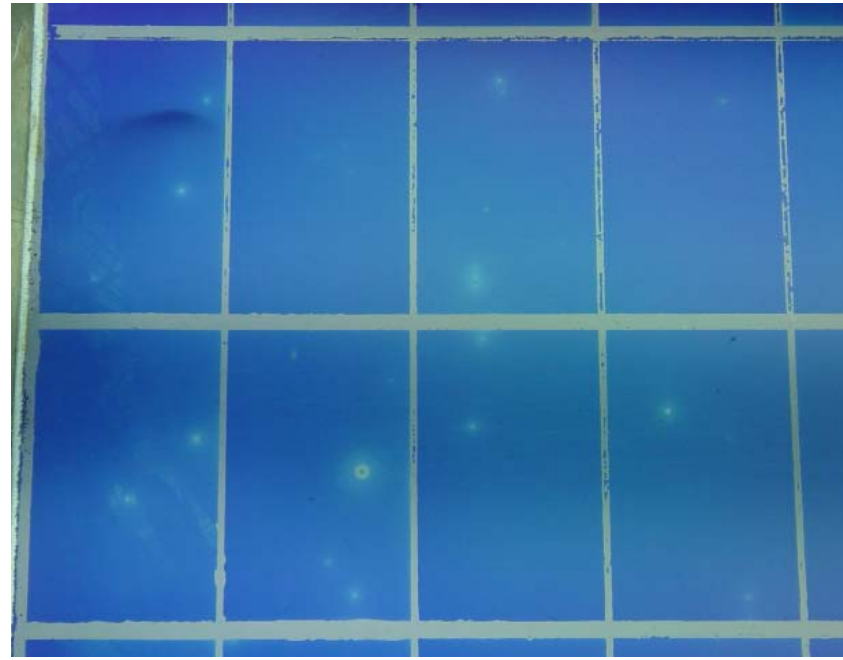
Shunt/Short Passivation Process



Developed a system to do shunt passivation using a photo-assisted electrochemical process. This process pin points the current-leaking shorts/shunts and convert the conductive oxide around the shorts/shunts into insulator, thereby electrically isolate such shorts/shunts.

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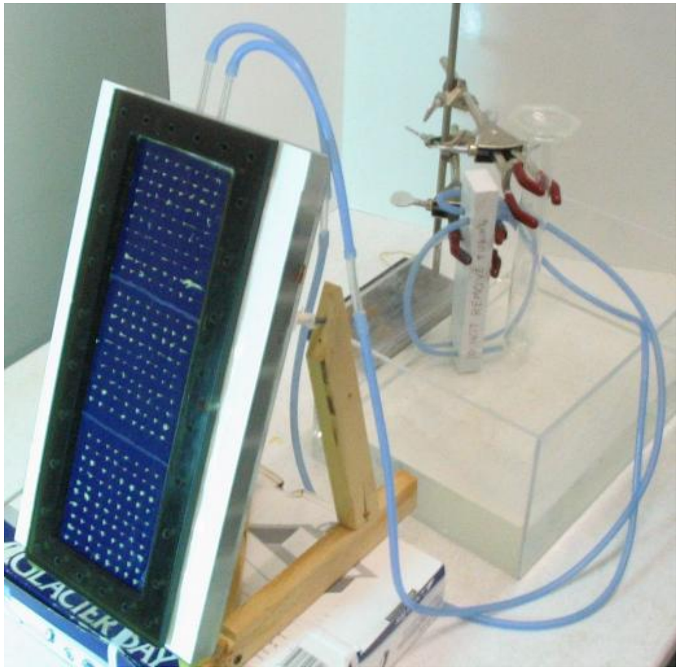
Hydrogen Production Rate



Previously reported PEC Cell:
Sample size: 4”x12”

H2 production rate: 6.2 cc/min under 0.82 sun intensity.

STH Efficiency: ~5%

We have previously reported substrate-type PEC cell with solar-to-hydrogen production efficiency of ~5%. The improved facility will allow MWOE to make larger PEC panels (e.g. 3ft x 3ft).

Future Work

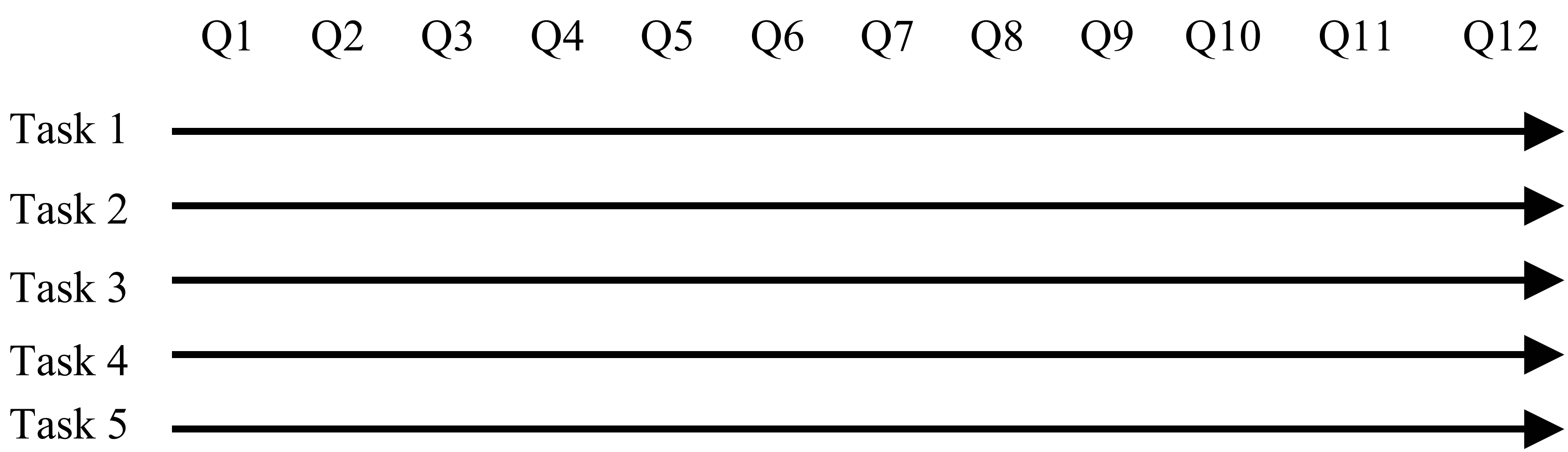
Task 1: Transparent, Conducting and Corrosion Resistant coating for triple-junction tf-Si based photoelectrode

Task 2: Hybrid multijunction PEC electrode having semiconductor-electrolyte junction

Task 3: Understanding and Characterization of photoelectrochemistry

Task 4: Fabrication of low-cost, durable and efficient immersion-type PEC cells and systems

Task 5: Fabrication of 8ft^2, substrate-type PEC panels



Effort will continue under all tasks.

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Team Members

- **Midwest Optoelectronics, LLC**

  Liwei Xu, Jason Day, Ken Draeger, Jason Justice, Mark McGilvery, Marty McClanahan, Richard Podlesny, Stanley Rubini, Aarohi Vijh, Carol Williams, Michael Yang

- **University of Toledo:**

  Xunming Deng, Alvin Compaan, Robert Collins, Dean Giolando, Maria Coleman and A.H. Jayatissa, Mahabala Adiga, William Ingler, Ling Hu

- **National Renewable Energy Laboratory**

  John Turner

- **United Solar Ovonic Corp.**

  Jeffrey Yang

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