Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

Protective Catalyst Systems on III-V and Si-based Semiconductors for Efficient, Durable Photoelectrochemical Water Splitting Devices

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November 14th, 2017

HydroGEN Kickoff Meeting

NREL National Renewable Energy Laboratory · Berkeley Lab · Sandia National Laboratories · INL Idaho National Laboratory · Lawrence Livermore National Laboratory · SRNL

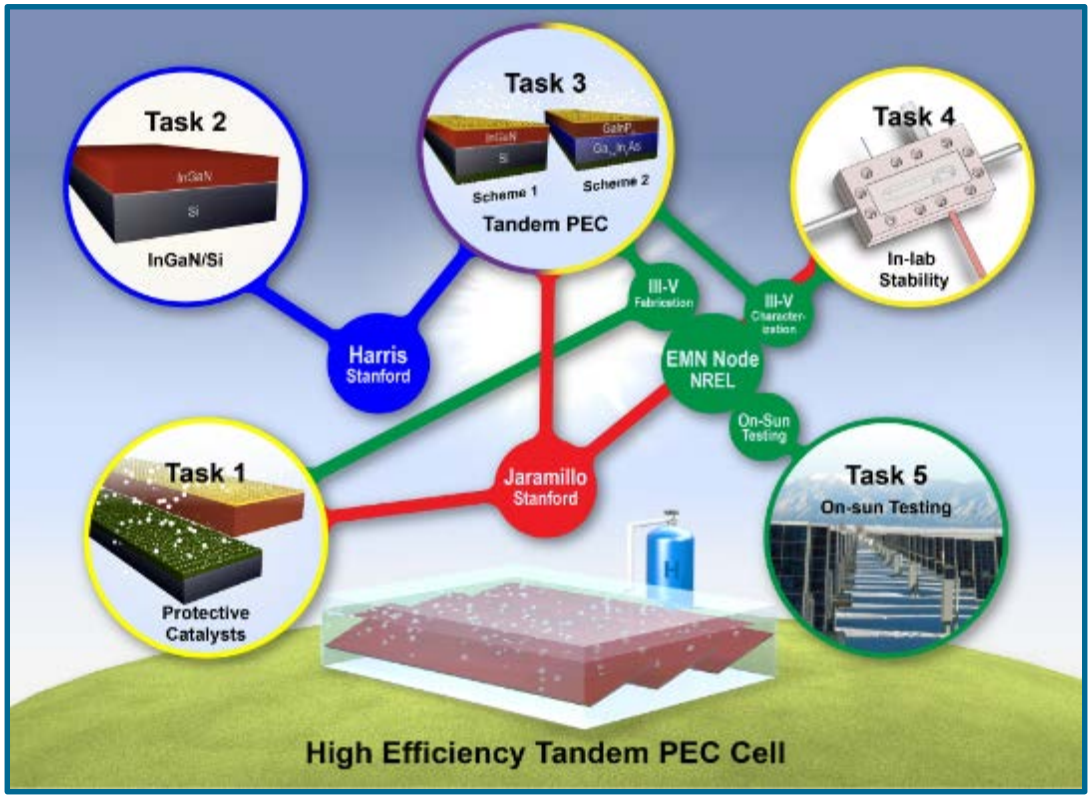
HydroGEN Kick-Off Meeting

Protective Catalyst Systems on III-V and Si-based Semiconductors for Efficient, Durable Photoelectrochemical Water Splitting Devices

Award #	EE0008084
Year 1 Funding	$250k

Thomas Jaramillo, Jim Harris

Stanford University



Project Vision

To develop unassisted water splitting devices that can achieve > 20% solar-to-hydrogen (STH) efficiency, operate on-sun for at least 2 weeks, and provide a path toward electrodes that cost $200/m^2 by incorporating earth-abundant protective catalysts and novel epitaxial growth schemes.

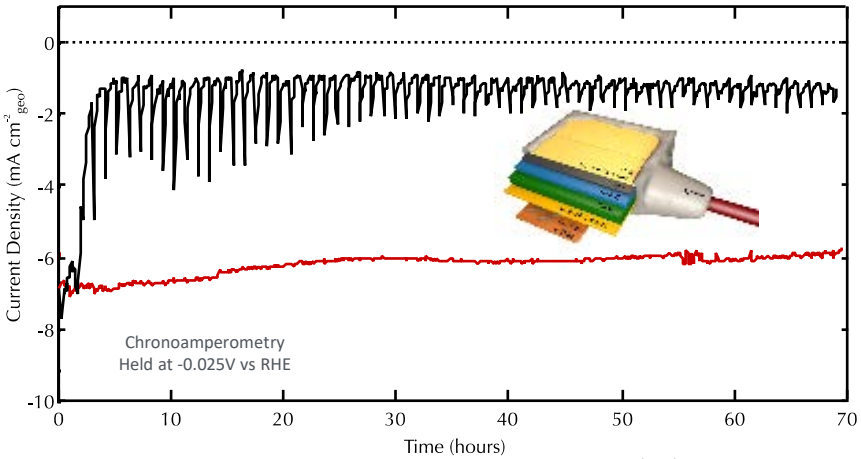
Project Impact

- Robust protective catalysts that stabilize III-V's in acid
- Tandem III-V/Si system that dramatically reduces cost
- On-sun data collection for weeks from a stable high performing unassisted water splitting device.

Innovation and Objectives

Project History

Collaborated with Todd Deutsch and James Young to stabilize GaInP photocathodes with MoS_2 protective catalysts



Reuben J. Britto, et. al. *J. Phys. Chem. Lett.* **2016** 7 (11), 2044-2049

Proposed Targets

Metric	State of the Art	Proposed
STH (III-V)	*16.7%* *Young, J. L. et al. Nat. Energy 2, 17028 (2017).*	*>20%*
Stability (III-V)	*~80 hrs* *Erik Verlage, et. al. Energy Environ. Sci., 2015,8, 3166-3172*	*2 weeks on sun*
Si/III-V tandem	Si-InGaN microwires *Nano Lett.*, **2012**, *12* (3), pp 1678–1682	High quality InGaN epitaxial growth on Si

Barriers

Stabilization of III-V surfaces in acid

Solution: Use MoS_2 and other non-precious protective catalysts that are stable in acid, sufficiently conductive, and active for the HER.

Fabrication scheme for high-quality InGaN growth on Si

Solution: Strategies such as graded buffer layers and nanoscale patterning for high quality InGaN growth on Si substrates.

Collecting on-sun data at the weeks time-scale

Solution: By stabilizing III-V unassisted water splitting devices for 100's of hours, we can test them outside for weeks.

Partnerships

Jaramillo Group

Electrochemistry, catalysis, protective layer expertise (characterization, catalysis deposition)

Harris Group

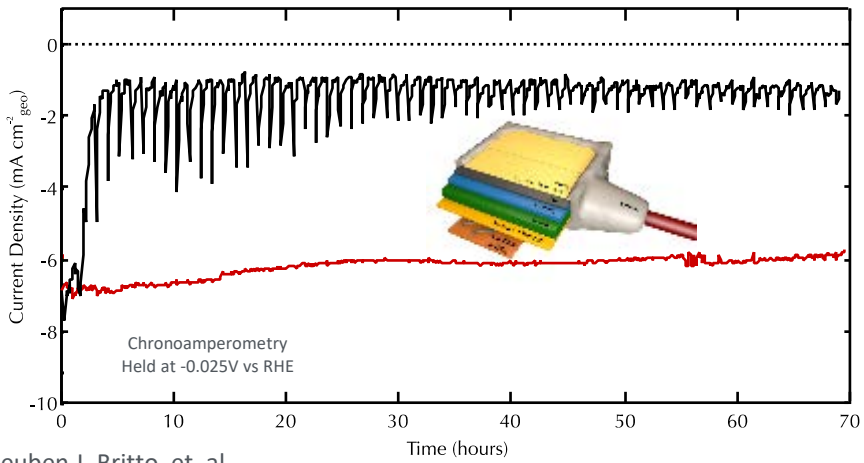
Semiconductor expertise, especially in novel fabrication techniques (InGaN growth)

NREL

III-V fabrication (epitaxial growth) expertise, on-sun testing expertise, unassisted water splitting device expertise

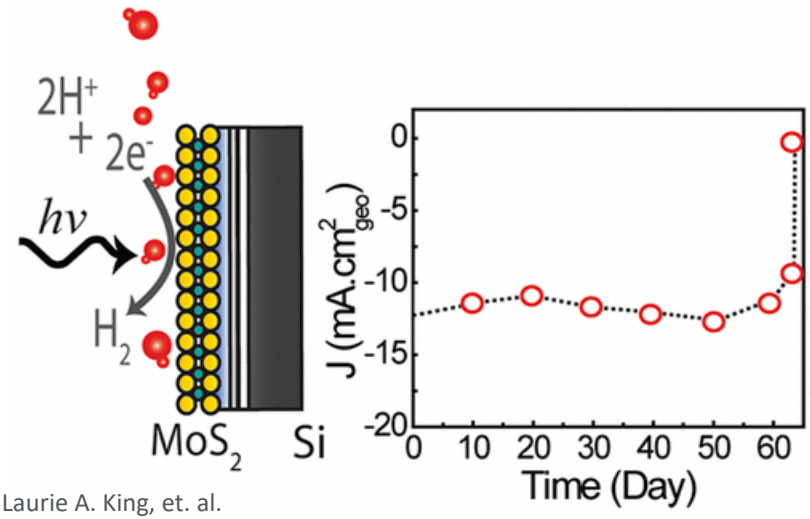
Project history: Collaborative efforts, prior work

NREL: Stabilizing GaInP with MoS_2



Reuben J. Britto, et. al.
J. Phys. Chem. Lett. **2016** 7 (11), 2044-2049

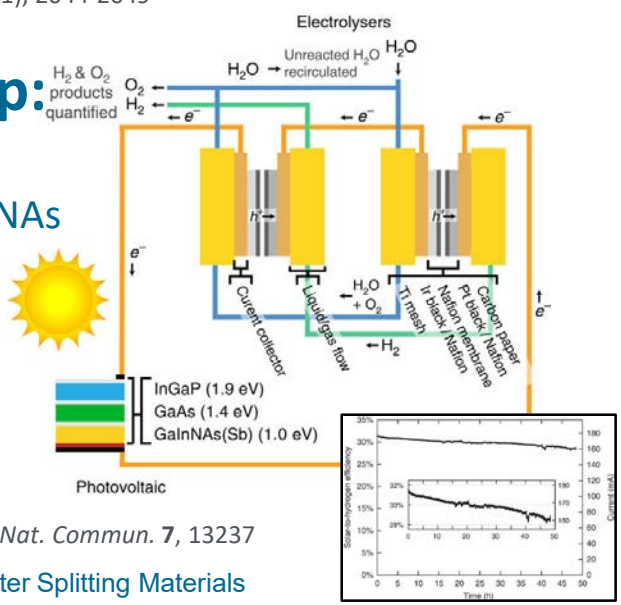
Silicon: Stabilizing Si with MoS_2



Laurie A. King, et. al.
ACS Appl. Mater. Interfaces, 2017, 9 (42), pp 36792–36798

Harris Group:

> 30% STH with a GaInP/GaAs/GaInNAs triple junction PV paired with dual electrolyzers.



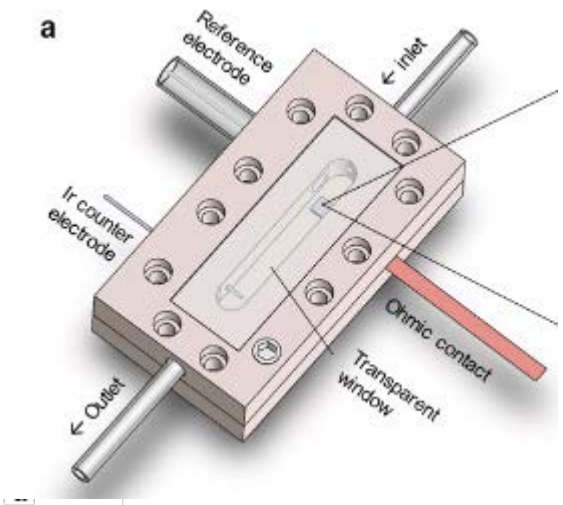
Jia, J. et al. *Nat. Commun.* **7**, 13237

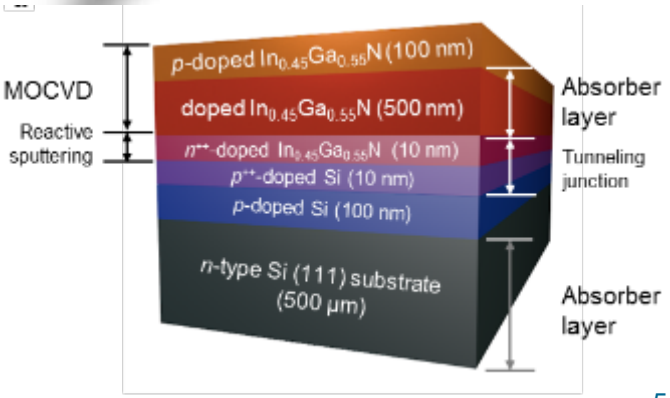
PEC Working Group:

Close engagement with the broader PEC community. To share technical progress, develop synergies, and collaboratively develop common tools and processes for PEC water splitting.

Barriers

- Stabilization of III-V surfaces in acid
  - Solution: Use MoS_2 and other non-precious protective catalysts that are stable in acid, conductive, and active for HER
- Fabrication scheme for high-quality InGaN growth on Si
  - Solution: Strategies such as graded buffer layers and nanoscale patterning for high quality InGaN growth on Si substrates
- Collecting on-sun data for weeks
  - Solution: By stabilizing III-V unassisted water splitting devices for 100's of hours, we can test them outside for weeks



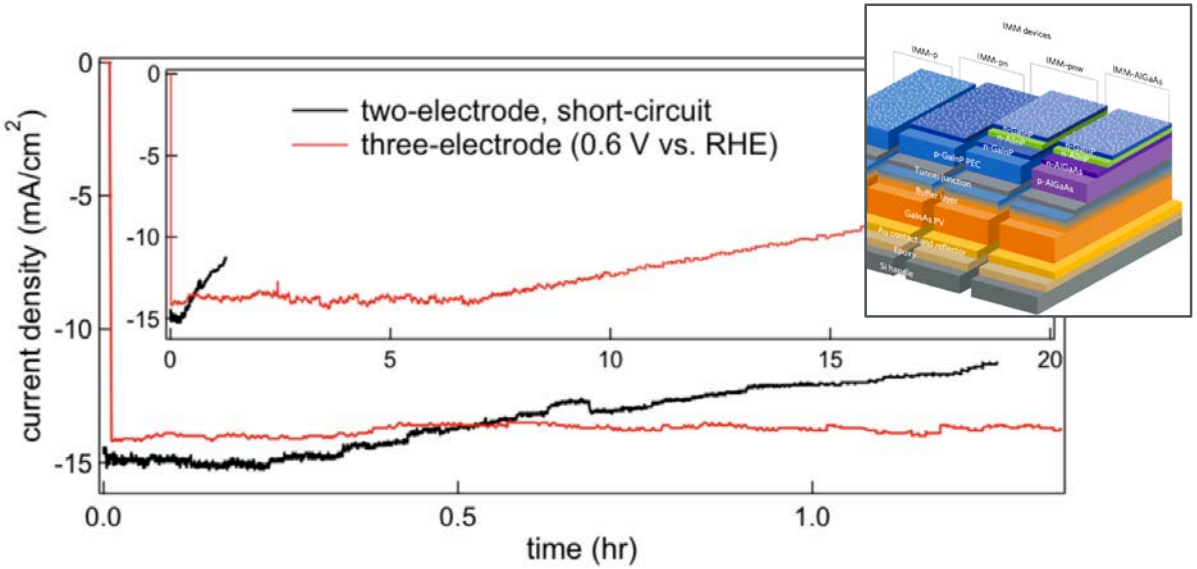


Technology Innovation

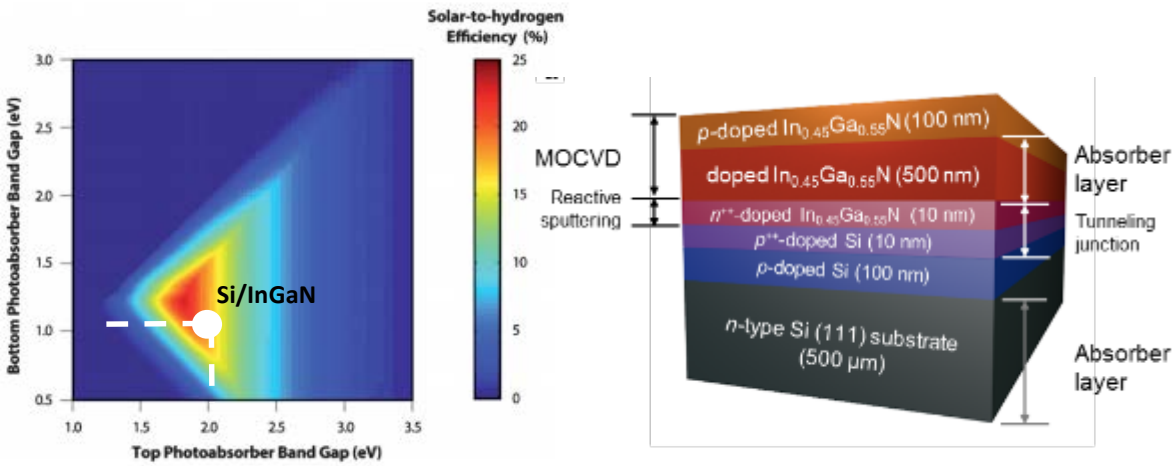
Technology Innovation:

Protect GaInP

By protecting GaInP, we can stabilize this record breaking 16.7% STH device, and leverage this to protect other III-V multi-junction systems with even higher efficiency.



James L. Young, Myles A. Steiner, Henning Döscher, Ryan M. France, John A. Turner, Todd G. Deutsch. Nature Energy. 2, 17028 (2017)



Technology Innovation:

High quality growth of InGaN on Si

A method to grow high quality InGaN on Si would provide a path toward >20% STH electrodes that cost $200/m^2

Blaise A. Pinaud, et. al. Energy Environ. Sci., 2013,6, 1983-2002

Effective Leveraging of the EMN Resource Nodes

- NREL: Characterization of Semiconductor Bulk and Interfacial Properties, ***Dr. Todd Deutsch***
  - Pre- and post- characterization and failure analysis of photocathodes and unassisted water splitting devices
- NREL: On-Sun Solar-to-Hydrogen Benchmarking, ***Dr. Todd Deutsch***
  - Testing station for collection of on-sun data for unassisted water splitting devices
- NREL: III-V Semiconductor Epi-structure and Device Design and Fabrication, ***Dr. Daniel Friedman***
  - Design and fabrication of III-V materials and systems
- The Jaramillo group has previously worked with all three EMN nodes to successfully protect GaInP photocathodes in acid

The Team!

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