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

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

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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/m² 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

**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.

**Proposed Targets**

<table>
<thead>
<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
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<tbody>
<tr>
<td>STH (III-V)</td>
<td>16.7%</td>
<td>&gt;20%</td>
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<tr>
<td>Stability (III-V)</td>
<td>~80 hrs</td>
<td>2 weeks on sun</td>
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<tr>
<td>Si/III-V tandem</td>
<td>Si-InGaN microwires</td>
<td>High quality InGaN epitaxial growth on Si</td>
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**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
HydroGEN: Advanced Water Splitting Materials

Project history: Collaborative efforts, prior work

**NREL:** Stabilizing GaInP with MoS$_2$

![Chroamperometry graph]

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

**Silicon:** Stabilizing Si with MoS$_2$

![Diagram of Si and 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.

![Graph of current density vs time]

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.

HydroGEN: Advanced Water Splitting Materials
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:

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.

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/m²
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