Energy Materials Network
U.S. Department of Energy

HydroGEN
Advanced Water Splitting Materials

HydroGEN 2.0 – PEC Technology Addressing Materials Stability and Device Durability

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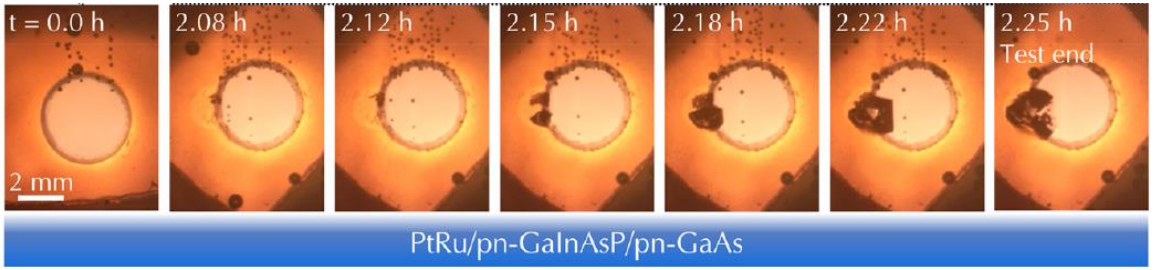
3/1/2021,
HydroGEN Advanced Water Splitting Technology Pathways Benchmarking and Protocols Workshop

NREL
BERKELEY LAB
Sandia National Laboratories
INL Idaho National Laboratory
Lawrence Livermore National Laboratory
SRNL Savannah River National Laboratory

Durability as critical barrier to the deployment of PEC



ACS Energy Lett. 2020, 5. 2631-2640

Outcome of the 2019 HydroGEN Benchmarking Workshop, the PEC Technology focus will be on: "*the understanding of degradation mechanisms and stressors and the development of standardized protocols*"

HydroGEN 2.0 PEC Technology

The PEC Technology in HydroGEN 2.0 will focus on identifying a **complete device assembly** and **near neutral pH conditions** to achieve **several hours of operation** at **high STH efficiency**

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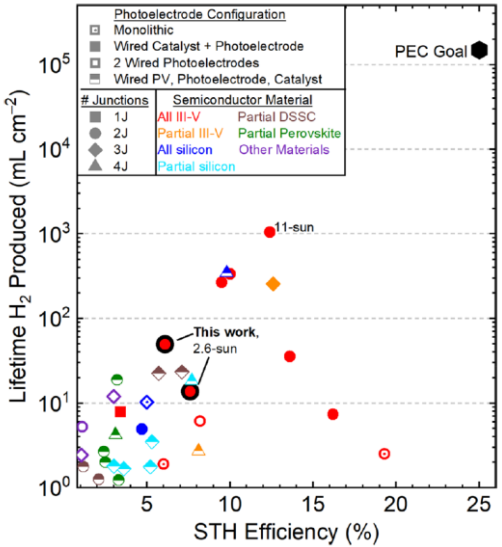

Comparison of the solar to hydrogen efficiency (STH) and lifetime H_2 produced for unassisted water splitting devices. The "PEC Goal" point in the upper right was calculated assuming a 20% capacity factor over a 10 year lifetime

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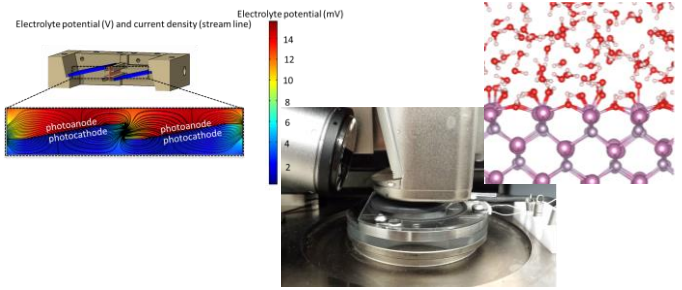
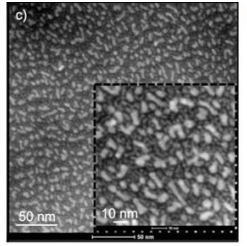
HydroGEN 2.0 PEC Technology

- Durability Protocol: We will focus on durability stressors and establish PEC device durability protocol

- Degradation Mechanism: We will provided theory guided mechanistic understanding of PEC device degradation combined with operando measurements



- Corrosion Mitigation: We will modify photoelectrodes with catalysts and protection layers



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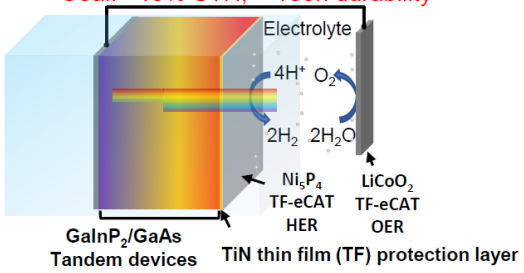
HydroGEN 2.0 PEC Technology

PI: Garfunkel/Dismukes

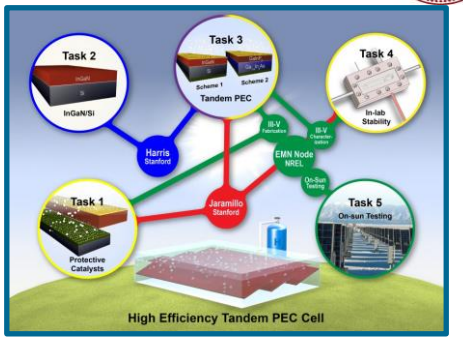
RUTGERS

High-Performance (HP) device
Goal: >10% STH, > 100h durability



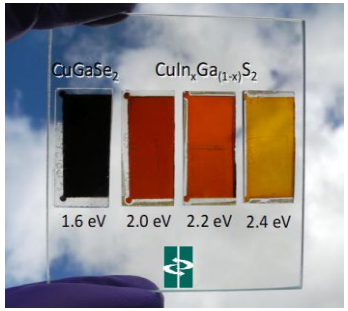
PI: Jaramillo

III-V based -- Goal: >20% STH, >14 days



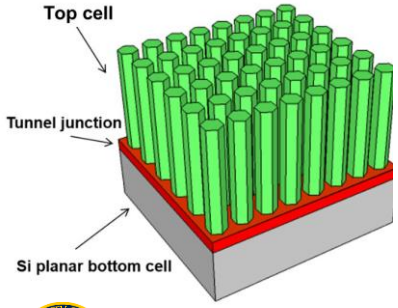
PI: Gaillard

chalcopyrites into efficient and low-cost PEC devices



PI: Mi

Si-based tandem -- Goal: >15% STH, >1000 h



UNIVERSITY of HAWAI'I MĀNOA

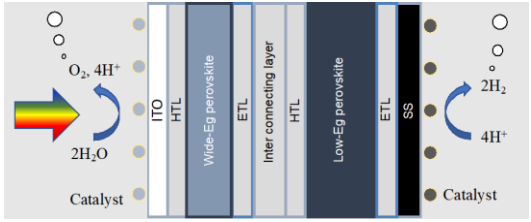
UNLV

THE UNIVERSITY OF TOLEDO

MICHIGAN STATE UNIVERSITY

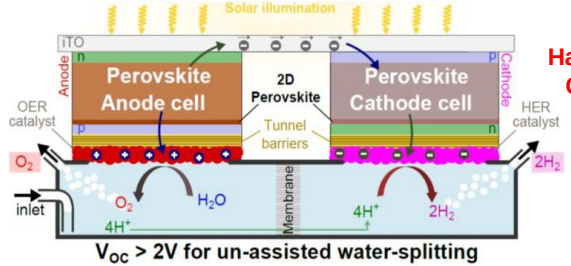
THE UNIVERSITY OF TOLEDO

PI: Yan



Halide perovskite -- Goal: >20% STH

PI: Mohite

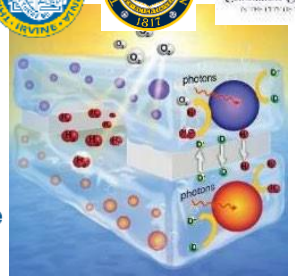


V_{oc} > 2V for un-assisted water-splitting

Halide perovskite -- Goal: >20% STH

RICE

PI: Ardo



Improve yield of particle PEC systems

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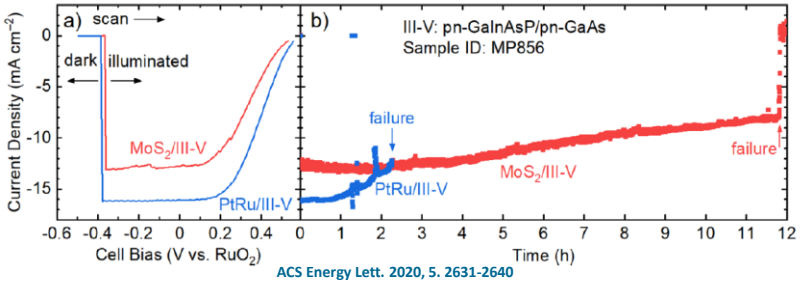
HydroGEN: PEC Tecnology Progress to Date with Seedlings

- Unassisted water splitting III-V based devices with nearly 12 hours stability (NREL/Stanford) – two-electrode stability testing



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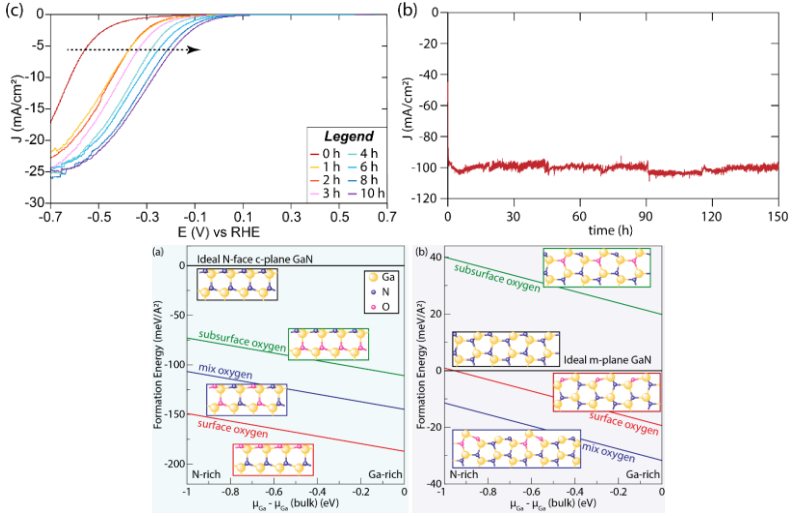
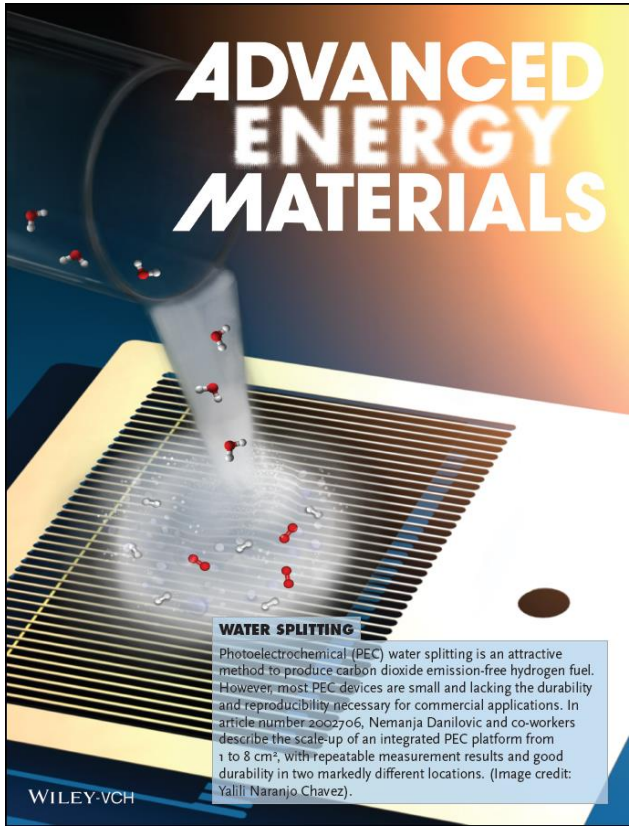
- Theory-guided understanding of chemical transformations of GaN/Si photocathodes that lead to enhanced catalytic activity and sustained operation (LBNL/LLNL/University of Michigan)



Nature Mater. 2021, in press

HydroGEN: PEC Tecnology Progress to Date – Supernode

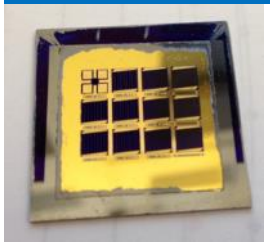
- Demonstrated scale up of integrated photoelectrochemical device based on III-V photoabsorbers and Pt and Ir catalysts
- Demonstrated device reproducibility at LBNL and NREL with indoor and outdoor testing
- PV degradation limits the long-term stability of the device



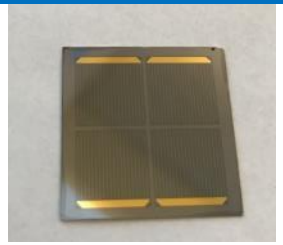
Adv. Energy Mater. 2020, 10, 2002706

HydroGEN: PEC Tecnology Progress to Date – Supernode

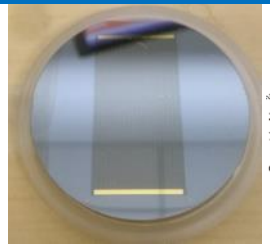
PEC Fabrication: GaInP/GaAs cells with 0.1 to 8-cm^2



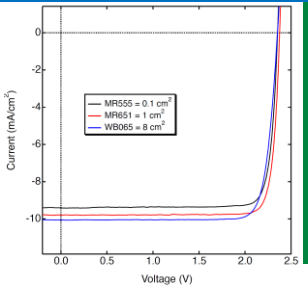
PV cells: ~0.1 cm^2



~1 cm^2



8 cm^2



- **These are the largest area III-V tandem cells made at NREL, enabling larger area PEC studies.**
- Significant effort toward developing growth recipes for uniform and high-quality GaInP.

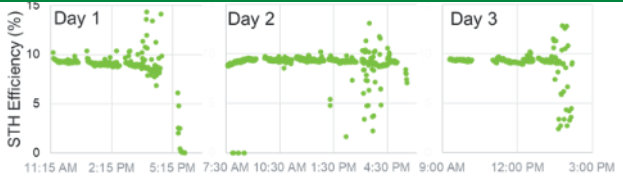
Scale Up Towards 8-cm^2 Illuminated Area

Degradation Modes Observed: 8-cm^2 Cell

- **Gold grid finger delamination**
- **Anti-reflective coating dissolution**
- **Bubbles in epoxy – more light scattering**
- **Blistering**

On Sun Durability Testing: 8-cm^2 Cell

- ***Test Duration:* 2 days, 2 hours, and 50 minutes**
- **Steady-state STH efficiency was 9.2%**



Emergent Degradation Phenomena Demonstrated on Resilient, Flexible and Scalable Integrated Photoelectrochemical Cells

Scientific Achievement

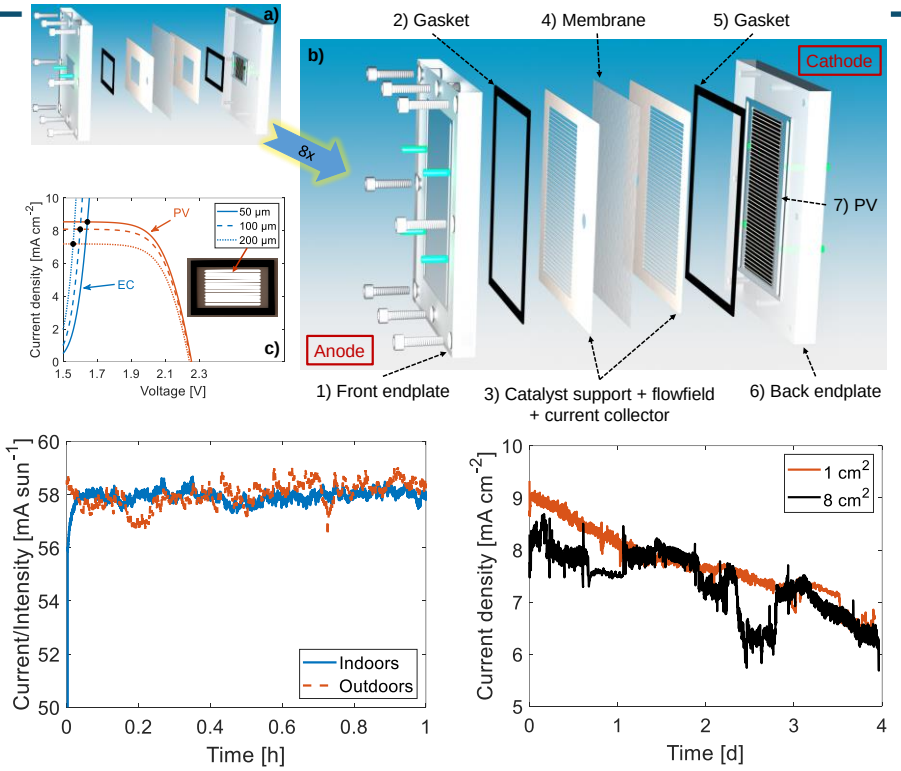
Designed, fabricated and characterized the largest integrated PEC (IPEC) H_2 reported to date, including on sun testing and assessment of performance loss mechanisms.

Significance and Impact

Successful IPEC device and PV cell fabrication scale up from 1 to 8 cm^2 with consistent performance in two geographies, in lab, and outdoors. Chemical processes associated with emergent degradation and pathways to mitigate them are identified.

Research Details

- Comparison between 1 and 8 cm^2 cells yields similar performance
- Indoor/outdoor and LBNL/NREL comparisons using identical 8 cm^2 cell prove the robustness of this design
- Degradation only visible during 4-day *accelerated stress test*
  - Failure analysis study shows that the aging of the epoxy barrier layer leads to penetration of water to the PV, causing hydroxylation and photocorrosion

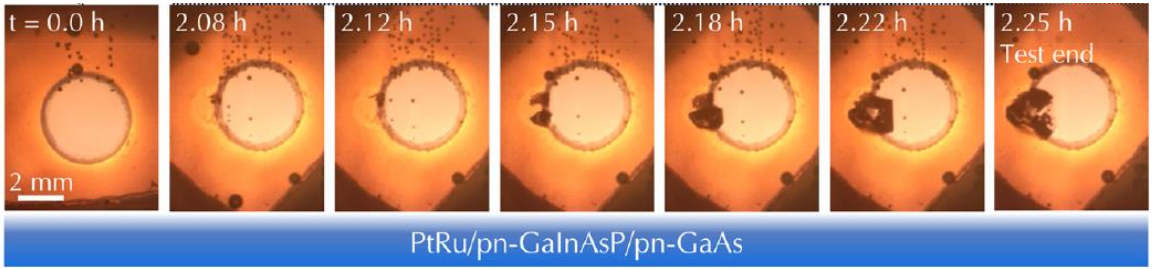


Schematic of the integrated photoelectrochemical cell and durability tests

T.A. Kistler and G. Zeng, J. L. Young, L. Weng, C. Aldridge, K. Wyatt, M. A. Steiner, O. Solorzano Jr., F. A. Houle, F. M. Toma, A.Z. Weber, T. G. Deutsch, N. Danilovic, Advanced Energy Materials, (2020), 10.1002/aenm.202002706

Summary

The PEC Technology in HydroGEN 2.0 will address durability as critical barrier to the deployment of PEC



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Through development of protocols, understanding of corrosion mechanisms, and development of mitigation strategies, NREL, LBNL, and LLNL will identify a complete device assembly and near neutral pH conditions to achieve several hours of operation at high STH efficiency

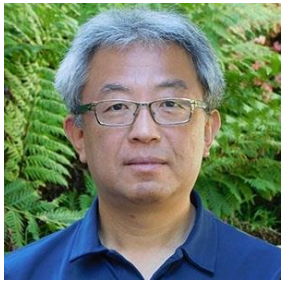
HydroGEN 2.0 PEC Team


Adam Weber


Ethan Crumlin


Francesca Toma

BERKELEY LAB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Lawrence Livermore National Laboratory

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Anh Pham (LLNL)

AWS Community

HydroGEN Advanced Water Splitting Materials