Towards High Solar to Fuel Efficiency

Wen-Hui Cheng, Matthias H. Richter, Matthias M. May, Jens Ohlmann, David Lackner, Ian Sullivan, David M. Larson, Chengxiang Xiang, Hans-Joachim Lewerenz , Frank Dimroth, Thomas Hannappel, Bruce S. Brunschwig, Harry A. Atwater

JCAP JOINT CENTER FOR ARTIFICIAL PHOTOSYNTHESIS

Abstract:

We demonstrated high solar-to-H2 efficiency in PEC devices, consisting of a III-V based tandem light absorber and RuOx/Rh NP catalysts for OER and HER. Minimizing parasitic light absorption and reflection losses with favorable band alignment further reduces the efficiency gap to the theoretical limit. We also developed a solar-driven CO2 reduction device using a gas diffusion electrode (GDE) with Ag nanoparticle catalyst directly powered by a III-V based triple junction solar cell. Device geometry was studied to extend the operation stability.

Introduction

To realize high solar-to-fuel efficiency in PEC devices, it is necessary to maintain a catalytic current density close to the light limiting photocurrent density for a solar-driven light absorber, which can be fulfilled when catalyst ensembles are highly transparent.

Solar-driven reduction of carbon dioxide represents a carbon neutral pathway for the synthesis of fuels and chemicals. A gas diffusion electrode (GDE) directly powered by a photovoltaic cell is a promising path to producing chemical fuels from CO2 and sunlight.

JCAP Team

Outlook

Solar-to-hydrogen efficiencies of 19.3% and 18.5% are obtained in acidic and neutral electrolytes. The system reaches a value of 0.85 of the theoretical limit for photoelectrochemical water splitting for the energy gap combination employed in the tandem-junction photoelectrode structure.

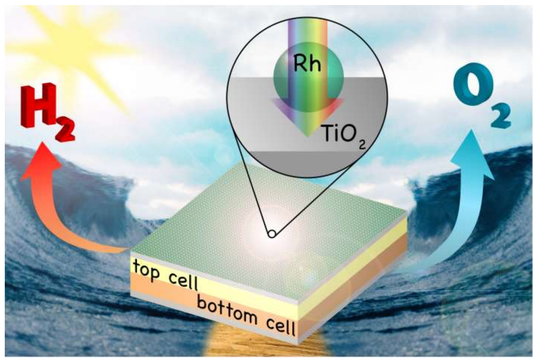
A solar-to-CO energy conversion efficiency of 19.1% is also achieved under simulated AM 1.5G illumination at 1 Sun. The use of a reverse-assembled GDE prevented transition from a wetted to a flooded catalyst bed and allowed the device to operate stably for >150 h with no loss in efficiency.

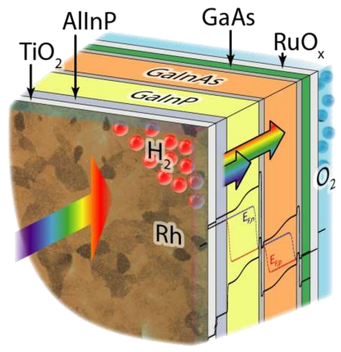
Acknowledgments

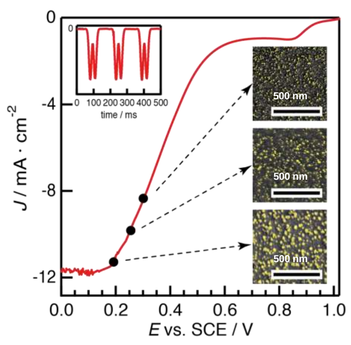
This material is based upon work performed by the Joint Center for Artificial Photosynthesis, a DOE Energy Innovation Hub, supported through the Office of Science of the U.S. Department of Energy under Award Number DE-SC0004993. Research was in part carried out at the Molecular Materials Research Center of the Beckman Institute of the California Institute of Technology.

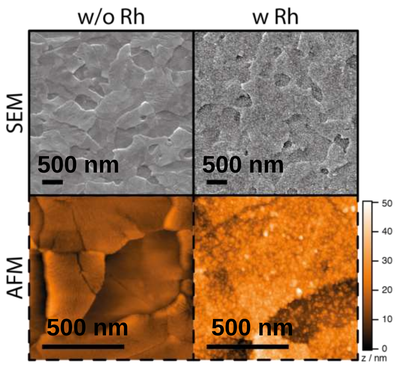
Results, Highlights, and Accomplishments

Monolithic Photoelectrochemical Device for Direct Water Splitting with 19% Efficiency

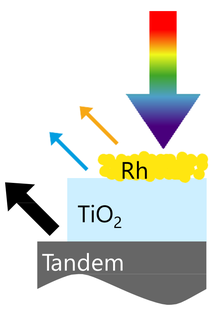


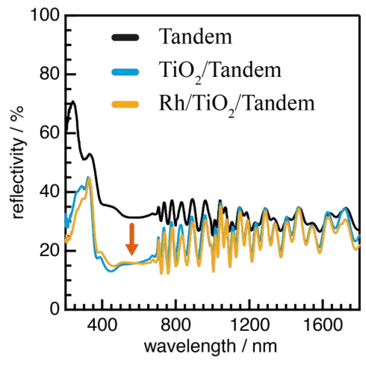


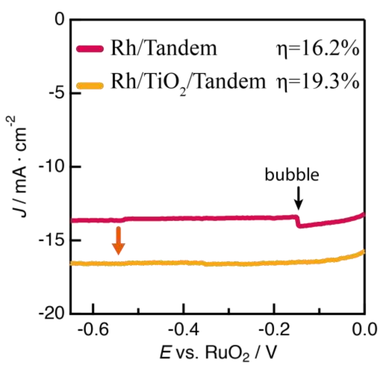




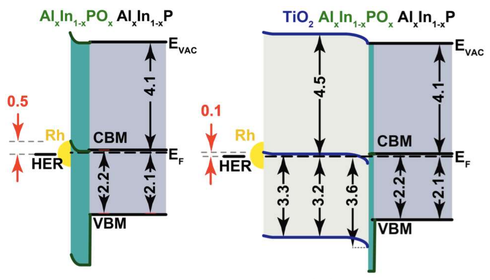
Fine control of particle size is achievable, optimized condition with ~10nm Rh is applied to the real device.

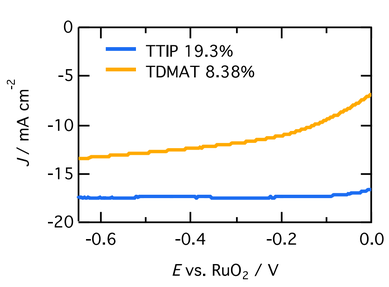


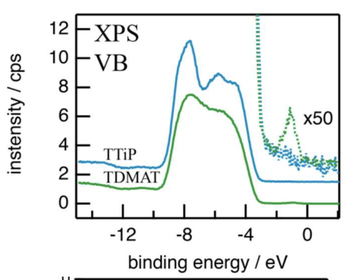


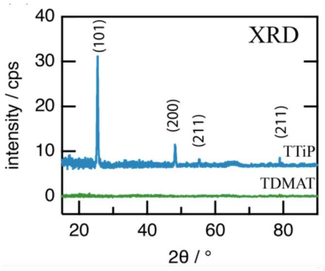


Successful incorporation of TiO_2 anti-reflection layer and effective transparent Rh catalyst, overall lead to high photocurrent and high efficiency.



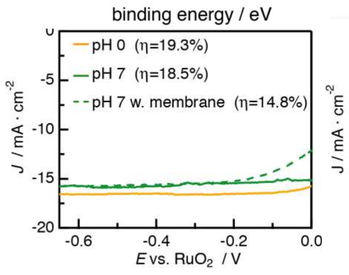


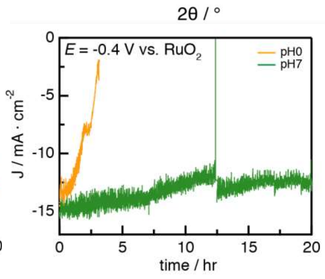


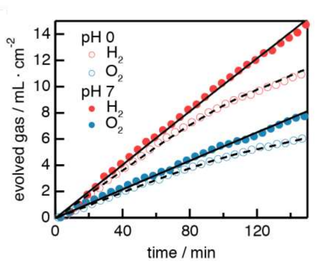


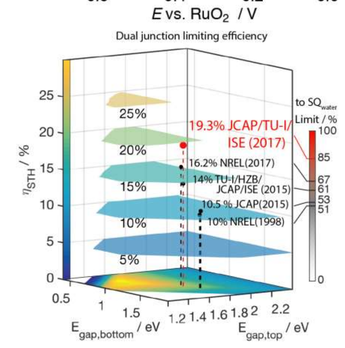
Defect band ➔ increases recombination ➔ reduce R_{sh}

Amorphous ➔ lower conductivity ➔ increase R_s







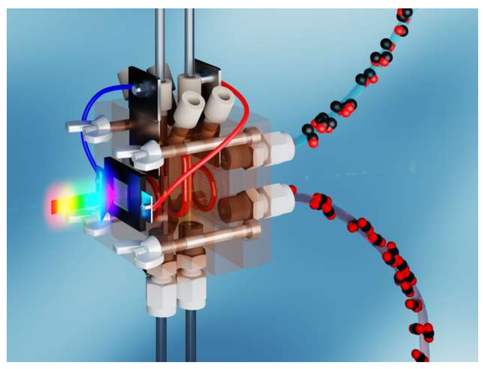


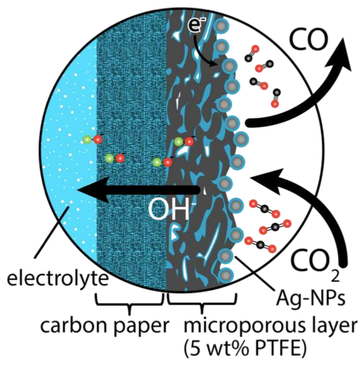
High efficiency unassisted water splitting in both acid and neutral pH conditions, extended stability achieved in neutral pH.

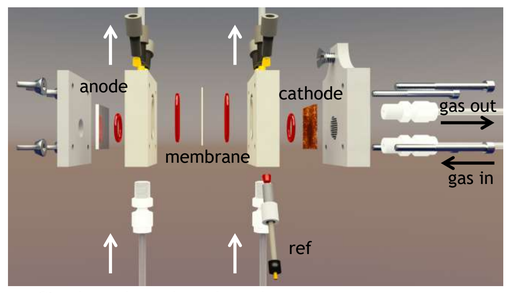
Near 100% faradaic efficiency towards Hydrogen and Oxygen production.

[ref] ACS Energy Letters 3 (8), 1795-1800, (2018).
DOI: 10.1021/acsenergylett.8b00920

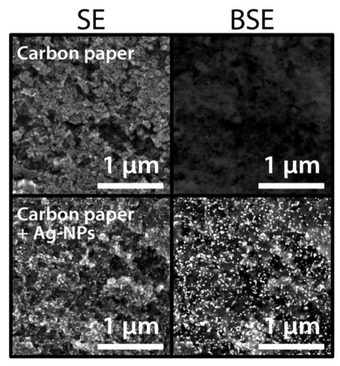
CO_2 Reduction to CO with 19% Efficiency in a Solar-Driven Gas Diffusion Electrode Flow Cell under Outdoor Solar Illumination



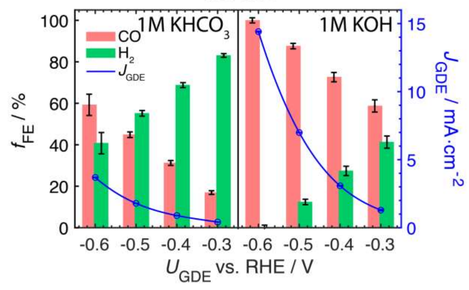




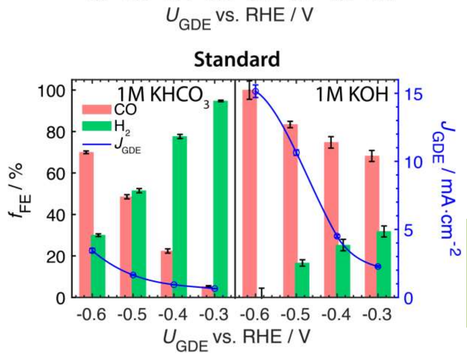
Circulate electrolyte through pump

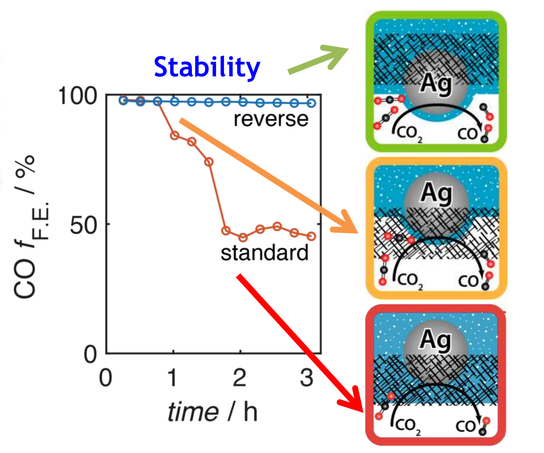


Reverse



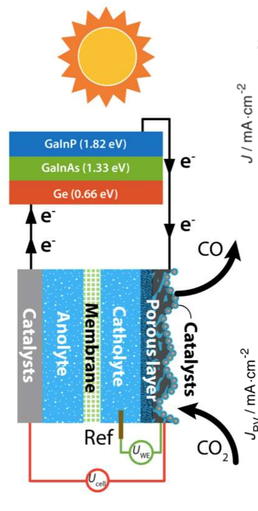
Standard

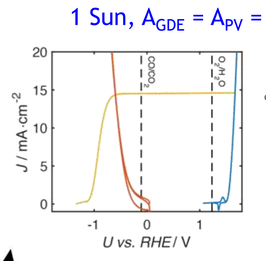


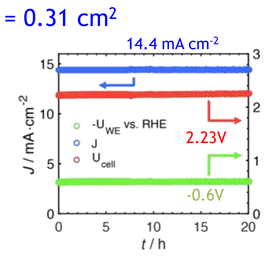


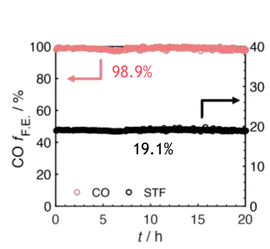
Standard-assembled GDE showed transition from wetted to flooded catalysts, resulted in a reduction of FE.

1 Sun, $A_{GDE} = A_{PV} = 0.31$ cm²

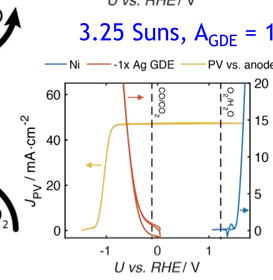


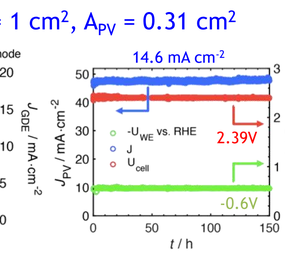


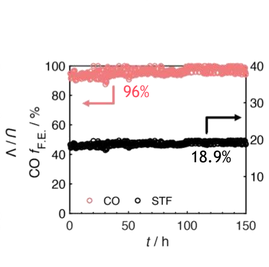


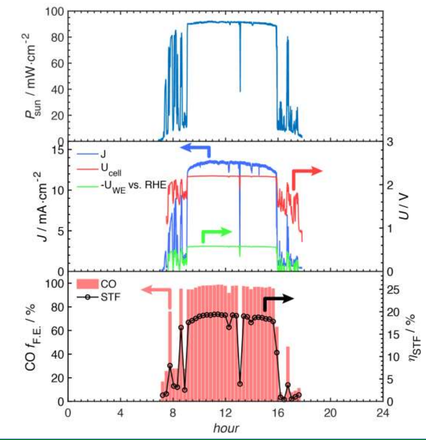


3.25 Suns, $A_{GDE} = 1$ cm², $A_{PV} = 0.31$ cm²

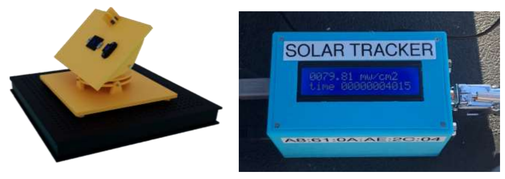








Outdoor test, $A_{PV} = A_{GDE} = 0.31$ cm²



Peak 6 h solar-to-CO efficiency 18.7%
CO production rate of 15 mg per day

[ref] ACS Energy Letters 5 (2), 470-476, (2020).
DOI: 10.1021/acsenergylett.9b02576