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SHINE

SOLAR HYDROGEN INTEGRATED NANO ELECTROLYSIS

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What it's about…

Developing an efficient and cost effective hydrogen production system that uses only sunlight and water as inputs.

Context and project goals

This project aims to develop a hydrogen production system using sunlight in an integrated manner with earth abundant materials mimicking natural photosynthesis. PhotoElectroChemical (PEC) systems use semi-conductor materials to absorb photons from the sun to generate a potential high enough (>1.2 V) to split water and produce hydrogen and oxygen at an integrated electrolysis cell. A major advantage of PEC systems over systems composed of photovoltaic panels (PV) in conjunction to a separate electrolyzer is their integral approach, i.e. the PV cell is part of the electrolyzer. This provides opportunities not only for cost reduction but also for improvement in the efficiency of the electrochemical reaction.

There are currently small-scale pilot production sites where hydrogen is produced with solar power in Switzerland. For example, the Michelin research center near Fribourg has 55 m^2 of photovoltaic panels with 15% efficiency. The electricity generated by the solar panels powers a potassium hydroxide electrolyzer running at 75% efficiency, producing hydrogen gas compressed at a pressure of 30 bars. The solar-to-fuel efficiency of such a pilot plant is thus 11.2%. The plant produces 1.56 kg of H_2 gas per day during the summer, which represents 52 kWh of energy. This is a large energy density, more than 20 times that of the best lithium ion batteries when accounting for the mass of the pressurized hydrogen composite container.

In 2010, an artificial photosynthesis program funded by the US Department of Energy received $122 million for 5 years, whose mission is to develop manufacturable solar fuel generators with earth abundant elements yielding sun to fuel efficiencies over 10% (ten times the fuel efficiency of natural crops). In Switzerland, Michelin since 2001 and Belenos since 2008 have teamed up with PSI to develop fuel cells and production of hydrogen gas with photovoltaic energy. Other research programs are underway in the EU, such as the German Research Foundation's SPP 1613 (2011).

We believe that leveraging the existing silicon photovoltaic knowhow in Switzerland and focusing on a system's engineering approach for manufacturing hydrogen via PEC will provide the tools to become an important player in a renewable-based fuel economy. Specifically, we propose a system's engineering approach for realizing a PEC system with:

- Photoharvesting electrodes based on amorphous and crystalline silicon cells developed in Prof. Ballif's group at CSEM which develops stable processes,oriented towards industry.
- PEC cell design inspired by fuel cell technology.
- Operation under concentrated sunlight.

Because of sunlight concentration (>10x), the reactor PV cells are smaller, more efficient and cheaper since less silicon semi-conductor material is used. Michelin research center is bringing a considerable practical experience in fuel cell and electrolysis in this project. The proposed system will make use of the full energy content of the solar spectrum by using the visible part of the spectrum (400 – 1000 nm) to illuminate the PV cell and the rest of the spectrum to self-align the concentrator and heat water to create water vapor near room temperature for the feedstock of the PEC cell. It is expected that the results of this project will provide the design tools and the technology blocks to produce efficient and cost effective sun-to-fuel systems.

How it differentiates from similar projects in the field

Much research effort has been devoted to the development of components of an integrated photo-electro-chemical system (PEC), but relatively little attention has been paid to the engineering-design aspects of viable solar-fuel generators.

Driven by physical and technoeconomic models, SHINE's systems engineering approach uses concentrated irradiation, thin film silicon cells and membrane electrode assembly water splitting units, optimized for an integrated operation, in order to obtain high sun to fuel efficiency at a low cost.

Quick summary of the project status and key results

In the first two years of the project, SHINE has developed the foundations to achieve viable solar-hydrogen generations. These achievements include:

- Development of coupled multi-physics, technoeconomic and energy life-cycle models that identify optimal design parameters for the fabrication of practical solar-hydrogen generators.
- Fabrication and small scale demonstration (5 cm x 5 cm) of a self-tracking solar-concentrator system with angular ranges above +/- 20°.
- Demonstration of a membraneless microfluidic electrolyzer for pure H_2 production.
- Development of water splitting devices that use humid air as feeds.
- Development of multi-junction microcrystalline and amorphous Si cells with open circuit voltages above 2.1 V (high voltages are required to drive the water splitting reaction) and efficiencies of 11%.
- Fabrication of photocathodes based on multi-junction Si photovoltaic materials and platinum as hydrogen evolution catalyst.
- Development of nickel based catalyst for water oxidation under alkaline conditions, and 3D printed water electrolysis cells based on membrane electrode assemblies.

Success stories

SHINE members, Volker Zagolla and Christophe Moser, at EPFL developed the first self-tracking solar-concentrator in the world.

Mohammad Hashemi, Miguel Modestino and Demetri Psaltis demonstrate the first membraneless water electrolyzers that produces pure Hydrogen streams. The work was featured in the cover of Energy and Environmental Science Journal.

SHINE members Artur Braun, Florent Boudoire and Rita Toth named among Foreign Policy magazine's "100 Leading Global Thinkers of 2014" for their work on solar-fuels.

Artur Braun co-organizes the Solar water-splitting symposium for the 2016 Materials Research Society Meeting in Phoenix, AZ, and assigned guest-editor to the MRS focus issue on this topic.

Christophe Moser, Demetri Psaltis and Miguel Modestino co-organized and chaired the special symposium on Solar Energy Conversion during the 2014 IEEE Photonics Conference in San Diego, CA.

Demetri Psaltis co-organized the 2015 European Optics Society Optofluidics conference, with special energy applications highlights.

Miguel Modestino is assigned as guest editor for the 2016 special issue on Solar-Fuels of the Journal of Physics D.

Awards:

Miguel Modestino receives the 2015 Energy and Environmental Science Readers' Choice Award for his work on technoeconomic aspects of Solar-Hydrogen generators.

Volker Zagolla wins the 2014 Light, Energy and Environment Congress Best Student Presentation Award from the Optical Society of America.

Presence in the media:

Work by SHINE members, Florent Boudoire and Artur Braun, at EMPA featured at RTS. -

Membraneless Electrolyzer work from SHINE members Mohammad Hashemi, Miguel Modestino and Demetri Psaltis featured in ChemistryWorld, EPFL and Technologist Magazine.

Work from SHINE members Florent Boudoire and Artur Braun featured in The Economist, Le Monde, La Liberte, Materials 360 online.

Rita Toth's work featured in the issue No. 105 of Swiss National Science Foundation Magazine, Horizons.

Main publications

V. Zagolla, E. Tremblay, and C. Moser, Proof-of concept for a self-tracking solar concentrator, OSA Technical Digest (online) (Optical Society of America, 2013), paper RT3D.2.

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V. Zagolla ; M. Schmidlin ; E. Tremblay ; C. Moser, Demonstration and future potential of a self-tracking phase change actuator, Proc. SPIE 8981 (doi:10.1117/12.2037623).

D. Dominé, L. Löfgren, M. Modestino, J.-H. Yum, P. Kohler, M. Benkhaira, L. Sansonnens, S. Nicolay, J. Bailat, C. Ballif, Thin-film silicon triple-junction solar cells for hydrogen production, Tech. Digest of the 6th World Conference on Photovoltaic Energy Conversion (WCPEC-6), Kyoto (JP), November 2014, p. 249.

M. A. Modestino, S. Haussener, An integrated device view on photo-electrochemical solar-hydorgen generation, Annual Review of Chemical and Biomolecular Engineering, 2015, 6 (1). (Invited Review).

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S.M.H. Hashemi, M. A. Modestino, D. Psaltis. , Membrane-less electrolyzer for pure hydrogen production across the whole pH range, Energy and Environmental Science, 2015, ASAP.

D. K. Bora, A. Braun and K. Gajda-Schrantz, Solar photoelectrochemical water splitting with bio-conjugate and bio - hybrid electrodes, Springer Book. "From Molecules to Materials—Pathway to Artificial Photosynthesis, 2014".

V. Zagolla ; D. Dominé ; E. Tremblay ; C. Moser, Self-tracking solar concentrator with an acceptance angle of 32°, Opt. Express 22, A1880-A1894 (2014).

"Cost-effective and integrated solar-hydrogen generator"