Photovoltaics for Hydrogen Production

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The SHINE Nano-Tera.ch project aims at the realization of a fully integrated solar-to-hydrogen system using thin-film silicon solar cells. Compared to a standard approach with discrete elements – with separate solar panels and electrolyzer – an improved efficiency might be expected thanks to the recycling of the dissipated heat from the solar cell using the same components.

A massive deployment of renewable energy technologies requires solving the present energy storage issue. This means finding a way to store a significant fraction of the annual world energy consumption.

A possible solution to elegantly store energy from sunlight in chemical bonds is the direct production of hydrogen using solar cells and water. Hydrogen can for instance be compressed, transported and stored; alternatively it can be injected in the gas distribution system as it is done, e.g., in a demonstration project in Germany.

The multi-disciplinary Nano-Tera.ch project SHINE involves several research groups within the fields of optics for solar, optics and fluidics, semiconductor solar cells, electrochemical materials and system simulation [1]. A system engineering approach based on system simulation is adopted to demonstrate a prototype consisting of 4 key elements, as symbolized in Figure 1, to be integrated in a compact photo-electro-chemical (PEC) system:

- An innovative solar concentrator with self-tracking, where light is trapped in a waveguide through a local phase change of paraffin wax, thermally activated.
- A photovoltaic solar cell made of a thin-film silicon multi-junction device, operating at its maximum power point with enough voltage to enable the electrolysis of water.
- Microfluidic for water feedstock with solar heat management for the cooling needed by concentration photovoltaics and the production of water vapour.
- An electrolyzer based on hydrogen- and oxygen-evolving electrodes and on a solid electrolyte made of a proton exchange membrane.

CSEM is in charge for the photovoltaic element of the system. A triple-junction device has been developed. It is made of a stack of two amorphous silicon subcells and one microcrystalline silicon subcell, and is optimized to achieve sufficient voltage for water splitting when loaded with the electrolyzer.

At one sun illumination, its open-circuit voltage is 2144 mV and the power density produced at the maximum power point is 11.3 mW/cm^2, leading to a potential water splitting efficiency of 8.1% [2]. This device has been successfully integrated in hydrogen production setups, so far leading to a stable solar-to-hydrogen conversion efficiency above 6% for over 20 hours.

In the project, alternative solutions to the triple-junction thin-film silicon will also be assessed, including a serial interconnection of small heterojunction crystalline silicon solar cells predominantly optimized for solar concentration. With this approach, solar-to-hydrogen conversion efficiencies above 15% can be expected, but making a fully integrated water splitting device is not desirable using this configuration due to the necessary cell interconnection. So far, we obtained direct solar-to-hydrogen conversion efficiencies up to 13.5%, fully relying on earth-abundant materials for device fabrication using a mini-module with three interconnected silicon heterojunction cells [3].

Improvements towards efficiencies up to and above 15% can for instance be expected by specific fine-tuning of the silicon heterojunction solar cell properties for the application of water splitting. Operating under concentrated sunlight should even further enhance device performance. A monolithic, fully integrated device using silicon heterojunction cells could for instance be made using a triple-junction cell with a silicon heterojunction cell as stable bottom cell with an excellent infrared response [4].

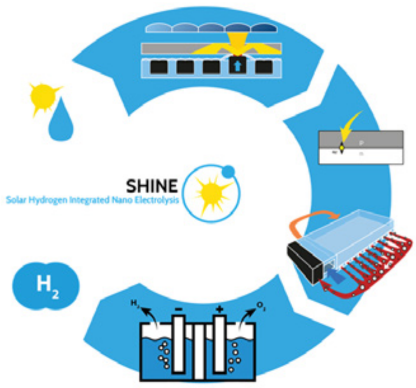

Figure 1: Conceptual view of the four elements of the integrated PEC device to produce hydrogen from solar energy and water [1] [5] [6].

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[1] www.nano-tera.ch/projects/367.php

[2] D. Dominé, *et al*., Proc. of WC PEC 6, Kyoto, Japan (2014)

[3] J.-W. Schüttauf, *et al*., Manuscript in preparation

[4] A. Smets, *et al*., Presented at ICANS26, Aachen, Germany (2015)

[5] According to the IEA, the world final energy consumption in 2011 was equal to 9 Gteo (105'000 TWh); see www.iea.org/publications/freepublications/publication/KeyWorld2013.pdf

[6] B. Burger, Fraunhofer Institute for Solar Energy Systems ISE, Electricity production from solar and wind in Germany in 2013, 12 August 2013