From research

Extract from the Annual Report 2023
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Hydrogen production by means of sunlight

Hydrogen is considered to be one of the most promising energy carriers for a sustainable and environmentally friendly energy supply. In this context, the utilization of sunlight as an energy source for hydrogen production is constantly gaining in importance. Direct solar water-splitting makes it possible to produce hydrogen by means of sunlight. It represents an alternative to the conventional method using photovoltaics and a downstream electrolysis unit. Within the framework of the Fraunhofer joint project "Neo-PEC", this technology was evaluated and further developed and a hybrid demonstrator was constructed.

Solar water-splitting

In direct solar water-splitting, a semiconducting material is brought into direct contact with an aqueous electrolyte. Through illumination with sunlight, energetically enhanced electrons and so-called holes are generated within the material. These reach the interface with the aqueous electrolyte where they trigger the chemical reactions for hydrogen and oxygen formation that are known from classic electrolysis.

In the simplest case, such a system can be realized using e.g. titanium oxide particles in an aqueous solution. The resulting gases reach the surface and can be collected there. The disadvantage of this procedure, however, is that oxyhydrogen gas is formed, an explosive mixture of oxygen and hydrogen.

Project approach

The aim of the "Neo-PEC" project was the development, in collaboration with the Fraunhofer Institute for Ceramic Technologies and Systems IKTS and the Fraunhofer Center for Silicon Photovoltaics CSP, of a new type of PEC module that will enable the cost-effective and clean creation of green hydrogen in the future and, consequently, a decentralized hydrogen supply.

The degree of efficiency should thereby be significantly increased, whilst the disadvantages of simple particulate systems and other very complex systems should be avoided and the costs significantly reduced.

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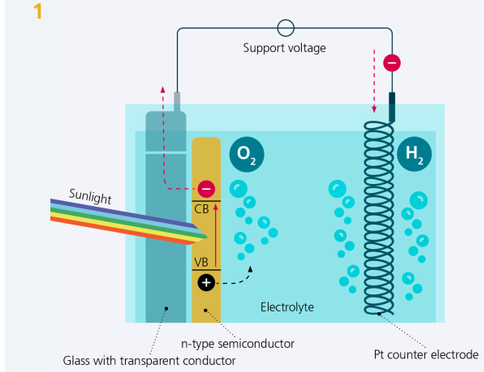

PEC half-cell structure with an n-type photoanode that is conductively connected to a platinum counter electrode. In this hybrid variant, a low auxiliary voltage is generally still required, provided e.g. by a solar cell.

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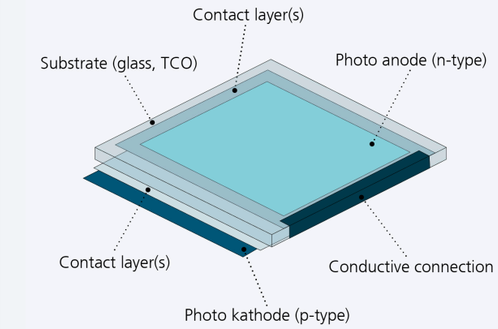

Illustration of a tandem cell consisting of an n-type and a p-type semiconductor on a contact layer and a transparent conductive oxide (TCO) for the creation of oxygen (anode) and hydrogen (cathode).

The chosen approach (see Figures 1 and 2) offers a simple structure and the advantage that hydrogen and oxygen can be produced and captured separately from one another, thereby avoiding the formation of oxyhydrogen gas.

The Fraunhofer IST contributed its expertise in the cost-effective large-area coating of high-quality semiconductor absorbers by means of physical vapor deposition (PVD). Initially, transparent carrier plates were coated with differing semiconducting materials that absorb sunlight, in order to produce hydrogen and oxygen.

Over the course of the project, the process was continuously optimized. The finished plates were subsequently integrated into a module with feed lines and discharge lines for the aqueous electrolyte and the resulting gases in order to demonstrate the entire system on a pilot-plant scale.

Results

Within the framework of the project, the Fraunhofer IST developed and optimized various semiconductor materials by means of sputtering processes:

- n-type semiconductors: $SrTiO_3$, TiO_2, $WMoO_3$, WO_3
- p-type semiconductors: $AgRhO_2$, $CuCrO_2$

Figures 3 to 5 exemplarily illustrate different morphologies of WMoO3, which were deposited at varying working points and examined by the Fraunhofer CSP with regard to their microstructure.

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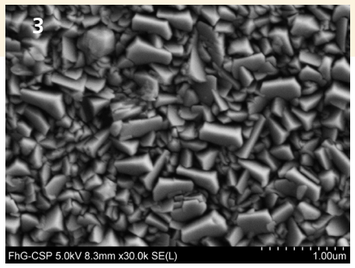

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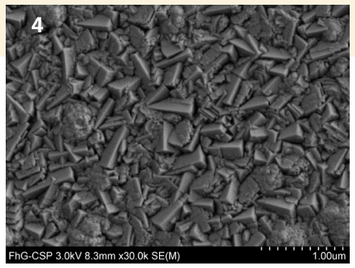

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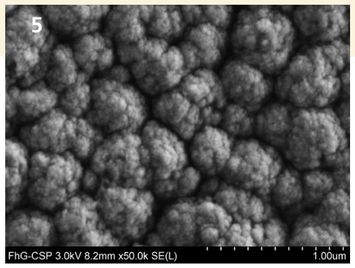

SEM images of WMO_3 photoanode manufactured at different working points. Photocurrent jphoto(2V vs. RHE): 0.935, 0.762 and 0.432 mA/cm², layer thicknesses: 1.88, 1.39, 1.86 µm, from left to right.

[1]Cheng et al., Monolithic Photoelectrochemical Device for Direct Water Splitting with 19% Efficiency, ACS Energy Lett. 3 (2018), 1795–1800.

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Neo-PEC

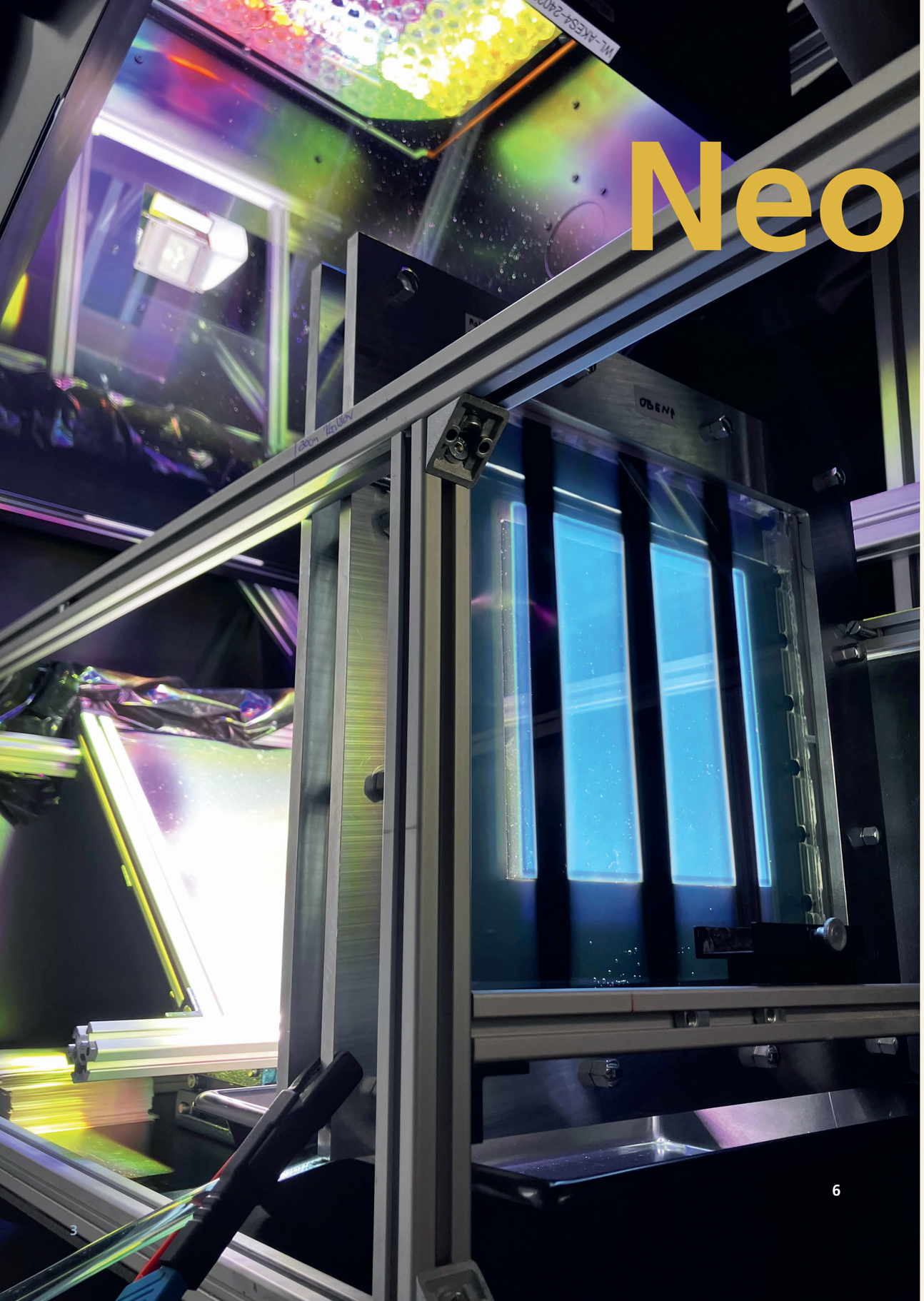
For the evaluation of the quality, the voltage-dependent photocurrent was used, which was measured in the so-called half-cell configuration at the solar-simulator test station and which is a direct measure of the hydrogen production. 1 mA hereby corresponds to 18.8 mg hydrogen. This was used to produce a segmented photoanode on a pilot-plant scale of 30 x 30 cm^2, with which a photocurrent of 150 mA at 2 V auxiliary voltage could be achieved (see Figure 7). Final work is currently being carried out on the integration of the photoanode and an adapted solar cell for the auxiliary voltage into the final PEC module.

Outlook

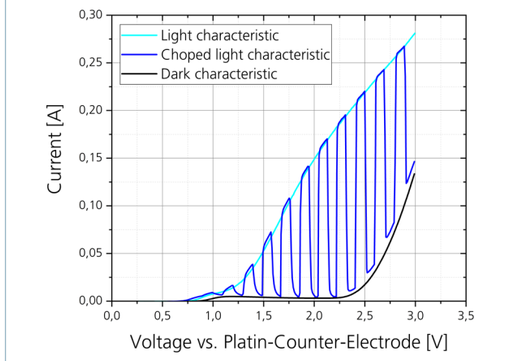
Within the framework of the project, it was possible to further expand the Fraunhofer IST's expertise in the development and realization of p-type and n-type semiconductors by means of the sputtering process and to demonstrate it in solar water-splitting. Prospectively, it will be necessary to further improve the quality of the photoanode (or cathode) in order to increase the hydrogen yield and to achieve a transition to semiconductors with a band-gap-related higher yield. In cooperation with partners, the Fraunhofer IST plans to continue its involvement in the development of efficient PEC modules and, consequently, to provide a further contribution towards the energy transition.

The project

The project Neo-PEC – Novel, large-area tandem PEC modules with dual Schottky junction for hydrogen production was funded internally by the Fraunhofer-Gesellschaft. It is a cooperation with the Fraunhofer Institute for Ceramic Technologies and Systems IKTS (production and provision of sputtering targets) and the Fraunhofer Center for Silicon Photovoltaics CSP (module construction and photoelectric characterization).



Demonstrator module with segmented photoanode for the measurement of photocurrent and hydrogen production in the solar simulator at the Fraunhofer CSP.



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Bias-voltage-dependent photocurrent (brightness characteristic) of the segmented photoanode under illumination with artificial sunlight. Measurement against titanium counter electrode in 1 molar perchloric acid ($HClO_4$), pH value < 2. The active area covers 455 cm^2.

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