Organometal halide perovskite-based photoelectrochemical module systems for unassisted solar water splitting

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Introduction

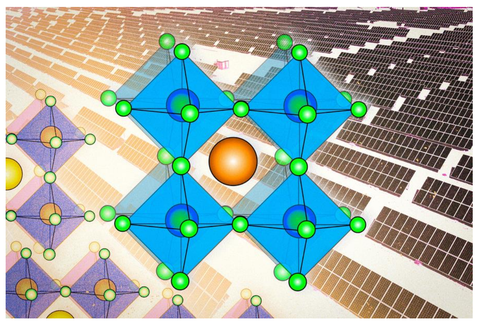
Organometal halide perovskites (OHPs) have emerged as promising materials for photoelectrochemical (PEC) water splitting due to their excellent optoelectronic characteristics. From the perspective of achieving efficient and unassisted solar water splitting – the final goal of PEC water splitting – OHP-based PEC systems are suitable to bridge the planning gap, due to the high photocurrent and photovoltage they can achieve.

Herein, we report OHP-based dual photoelectrodes by connecting the OHP photoanodes and photocathodes. The OHP-based dual photoelectrodes were encapsulated by catalyst-integrated metal foil encapsulation layers to protect OHP-based photoelectrodes against to water molecules and promote the kinetics of water splitting. Fabricated OHP-based dual photoelectrodes achieved high photocurrent density of 8.75 mA cm^{-2} and solar-to-hydrogen conversion efficiency (STH) of 10.4% without external bias.

However, these high PEC performance and long-term PEC stability using OHP-based dual photoelectrodes were achieved only in a small-scale laboratory environment (0.5 cm^2). Scalable OHP-based PEC systems are still challenging due to significant resistive losses as the active area of OHP PV cells, which are required to fabricate photoelectrodes increases. For large-scale OHP-based PEC systems, we introduce a novel modularization method. By connection of 16 optimized OHP photoelectrodes, including OHP photoanodes and photocathodes, we developed OHP-based PEC module systems (OHP module) for the first time. Developed OHP module of 4 cm^2 active area exhibited a photocurrent of 11.52 mA without external bias under natural sunlight.

Organometal halide perovskites (OHPs): Breakthrough active material of photoelectrodes for solar water splitting

OHPs are promising materials for solar water splitting due to their exellent optoelectronic properties

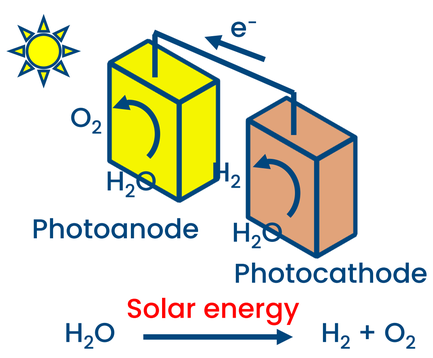


Linfeng Pan et al., Nat. Catal., 1 (2018)

OHPs have these properties
- Narrow and direct bandgap
- Strong ligh absorption
- Low trap density
- Weakly bound exciton
- Large diffusion length
- Suitable band position for solar fuel production

Unassisted solar water splitting: Ultimate goal of solar water splitting

OHP-based dual photoelectrodes can achieve higher solar-to-hydrogen efficiency (STH) than conventional photoelectrodes ($BiVO_4$, TiO_2, WO_3, Fe_2O_3, Cu_2O, $CuBi_2O_4$, CIGS, CZTS, etc.)



Requirements to drive unassisted solar water splitting
- High photocurrent
- High photovoltage (Low overpotential)

1.5–1.9 V is required to drive unassisted solar water splitting

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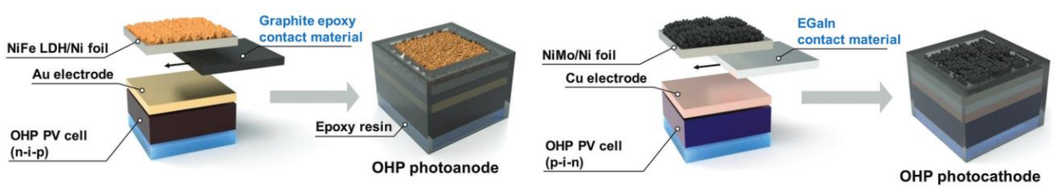
OHP dual photoelectrodes can close the planning gap

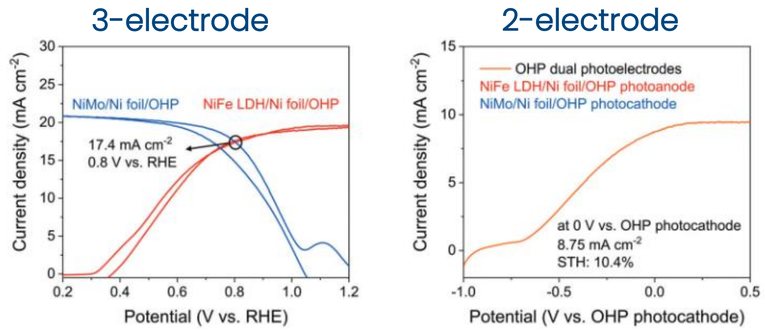
Experimental procedures

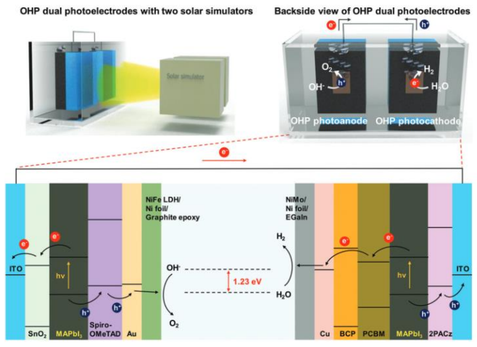
OHP dual photoelectrodes with catalysts-integrated metal foil encapsulation



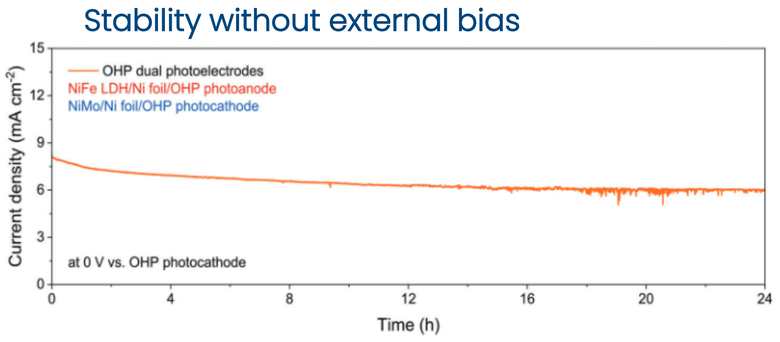
Results

PEC performance of OHP dual photoelectrodes





Stability without external bias



- **A photocurrent density of 8.75 mA cm^{-2} and STH of 10.4%** at without external bias were achieved
- **Long-term PEC stability over 24 h** without external bias

Necessity of OHP-based PEC module systems

High performance, **but only 0.5 cm^2 of small-scale device**

Hiroshi Nishiyama et al., Nature, 598 (2021)

How to achieve large-scale OHP-based PEC systems?

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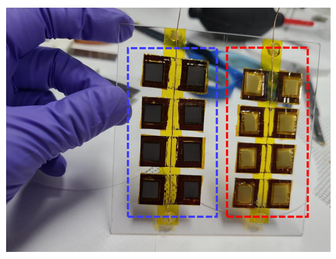
We introduced OHP PEC module systems!

Construction and real-world verification of OHP PEC module systems



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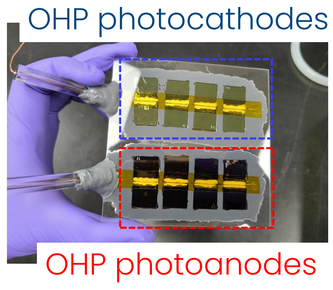
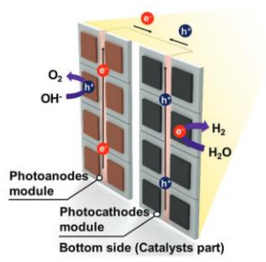
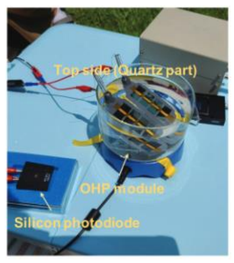
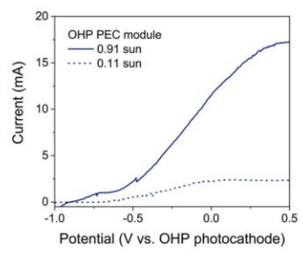
OHP photocathodes

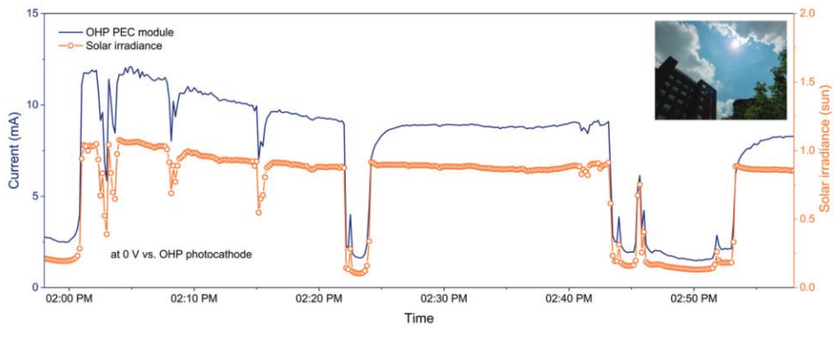


OHP photoanodes









- OHP module was constructed by parallel connection **of total 16 devices of OHP photoelectrodes** (8 OHP photoanodes + 8 photocathodes)
- OHP module generates **a photocurrent of 11.52 mA without external bias** under natural 0.91 sun
- **Successful operation** of OHP PEC module under **discontinuous natural sunlight**

Conclusions

- OHP dual photoelectrodes exhibited **10.4% of STH at unassisted condition**
- As new approach for **efficient and scalable unassisted OHP-based PEC systems, the OHP PEC module systems** were introduced in this study
- OHP PEC module generated **a photocurrent of 11.51 mA under 0.91 sun of natural sunlight without external bias**

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