Integrated tandem solar cells for low cost and high efficiency solar water splitting

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To encourage practical implementation of solar hydrogen production The U.S. Department of Energy has targeted solar-to-hydrogen (STH) conversion efficiency of 15% based on robust and low-cost resources [1]. Considering the losses associated with the reaction mechanism, a single semiconductor material with bandgap of around 2.2eV is needed for solar water splitting [2-4]. The use of a single semiconductor with sufficient bandgap to allow water splitting restricts us to the UV part of solar spectrum, thereby reducing the STH efficiency limit to 10% [5].Use of tandem structures can substantially enhance the STH efficiency of the system[6]. Tandem structure use a larger proportion of the solar spectrum with ideal theoretical STH efficiencies above 30% for mechanically stacked tandems with a silicon bottom cell [7, 8]

Most of the high efficiencies reported using tandem structures utilize III-V semiconductors [9] thus increasing the system cost. Use of perovskite-Silicon tandem cell offers a good alternative. Recently a record efficiency of 26% is being achieved by ANU for four terminal tandem structure.[10]. It can reduce the system cost without compromising on the efficiency. Tandem structure based on a top perovskite PV cell with a band gap of ~1.73 eV and a bottom Si photoelectrode could achieve a STH production efficiency of above 20% [11].

Ideal catalysts for solar water splitting are noble metal Pt for Hydrogen evolution reaction (HER) and IrO_2 and RuO_2 for the oxygen evolution reaction (OER). However, high cost restricts their implementation on large scale. Replacing precious metal catalysts with Earth abundant materials can substantially reduce the cost. Duan et. al. have shown non-precious metal based catalysts can have competitive performance to the above-mentioned standard expensive metal based catalysts[12].

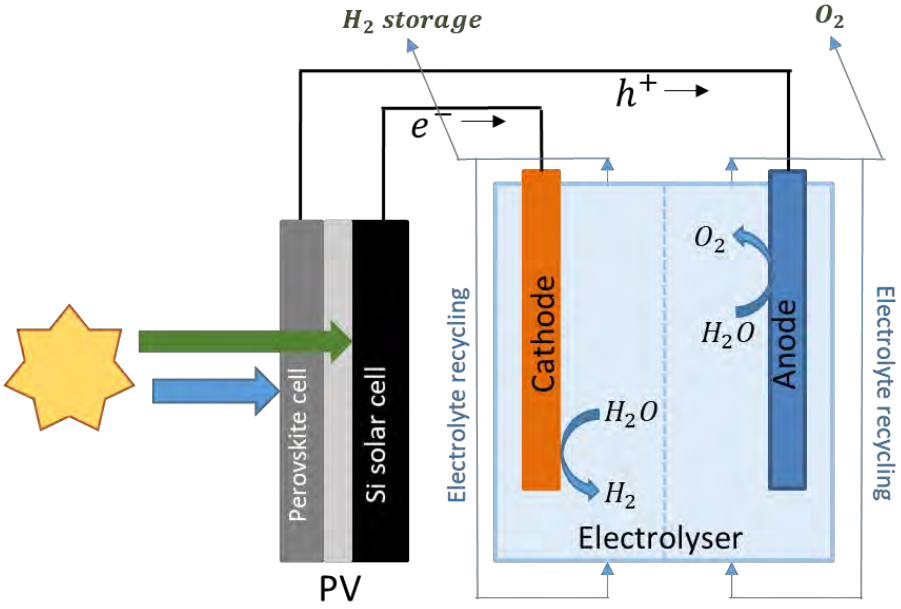

Fig 1- *PV Electrolysis, in which a photovoltaic tandem cell is electrically connected with an electrolyser*

We demonstrate, bias-free PV-Electrolysis system using low cost Perovskite-Silicon tandem cells and Ni-Fe based Earth abundant low-cost catalysts enabling solar hydrogen production. This system offers simple architecture and provides the freedom to design cells, fulfilling the photovoltage requirement to drive solar water splitting without any external bias. This system uses the advantage of high open-circuit voltage provided by perovskite-Silicon tandem cells [13].

We further explored and develop new interconnection strategies specifically designed to maximize the efficiency of solar hydrogen generation. Two terminal and four terminal tandem structures have been studied. It has been observed that among the different types of tandem architectures, the mechanically-stacked four-terminal (4-T) have lower restrictions on fabrication process and current matching compared to the two-terminal (2-T) architecture, and provides much more elasticity for each sub-cell assembly design. [10, 13, 14].These cells offer a better approach towards photovoltage and current matching for water splitting reaction. The performance of the as-developed system is critically assessed using gas chromatography and photo-electrochemical characterisation.

References:

1. *Hydrogen, fuel cells & infrastructure technologies program*. 2009; Hydrogen production, DOE/GO-102007-2430. p. 3.1e20:[Available from: http://www.eere.energy.gov/hydrogenandfuelcells/mypp.
2. Walter, M.G., et al., *Solar Water Splitting Cells.* Chemical Reviews, 2010. **110**(11): p. 6446-6473.
3. Gratzel, M., *Photoelectrochemical cells.* Nature, 2001. **414**(6861): p. 338-344.
4. Bolton, J.R., S.J. Strickler, and J.S. Connolly, *Limiting and realizable efficiencies of solar photolysis of water.* Nature, 1985. **316**(6028): p. 495-500.
5. Fujishima, A. and K. Honda, *Electrochemical photolysis of water at a semiconductor electrode.* nature, 1972. **238**(5358): p. 37.
6. Minggu, L.J., W.R. Wan Daud, and M.B. Kassim, *An overview of photocells and photoreactors for photoelectrochemical water splitting.* International Journal of Hydrogen Energy, 2010. **35**(11): p. 5233-5244.
7. Fountaine, K.T., H.J. Lewerenz, and H.A. Atwater, *Efficiency limits for photoelectrochemical water-splitting.* Nature communications, 2016. **7**: p. 13706.
8. Hu, S., et al., *An analysis of the optimal band gaps of light absorbers in integrated tandem photoelectrochemical water-splitting systems.* Energy & Environmental Science, 2013. **6**(10): p. 2984-2993.
9. Ager, J.W., et al., *Experimental demonstrations of spontaneous, solar-driven photoelectrochemical water splitting.* Energy & Environmental Science, 2015. **8**(10): p. 2811-2824.
10. Duong, T., et al., *Rubidium Multication Perovskite with Optimized Bandgap for Perovskite-Silicon Tandem with over 26% Efficiency.* Advanced Energy Materials, 2017. **7**(14): p. 1700228.
11. Fiona J.Beck, A.S., *Rational integration of photovoltaics for solar hydrogen generation.* to be presented in asia pacific solar research conference, 2018.
12. Duan, J., S. Chen, and C. Zhao, *Ultrathin metal-organic framework array for efficient electrocatalytic water splitting.* Nature communications, 2017. **8**: p. 15341.
13. Wu, Y., et al., *Monolithic perovskite/silicon-homojunction tandem solar cell with over 22% efficiency.* Energy & Environmental Science, 2017. **10**(11): p. 2472-2479.
14. Shen, H., et al., *Mechanically-stacked perovskite/CIGS tandem solar cells with efficiency of 23.9% and reduced oxygen sensitivity.* Energy & Environmental Science, 2018. **11**(2): p. 394-406.