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Tandem photovoltaic-photoelectrochemical device for solar hydrogen generation

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Abstract

We demonstrate highly efficient photovoltaic-photoelectrochemical (PV-PEC) tandem device based on GaAs/InGaAsP (PV cell) and $WO_3/BiVO_4$ core/shell nanorods (PEC cell), where PV cell operates under reflected light. The PEC-PV tandem shows stable water splitting photocurrents of 6.56 mA cm^{-2} at 1 sun (25 ^oC) and 18.17 mA cm^{-2} at 3 suns (50 ^oC corresponding to the solar to hydrogen (STH) conversion efficiencies of 8.1% and 7.5%, respectively, that are up-to-date record efficiencies among PV-PEC devices. We also show that infrared light can contribute to water splitting by heating the cell and improving reaction kinetics.

1. Introduction

Rapid growth of PV electricity generation capacities creates many challenges related to grid instabilities due to variability of PV output. For that reason storage of solar energy in a form of hydrogen that is generated via PV assisted photocatalytic water splitting is considered as a promising approach to compensate intermittency of the PV electricity supply with a benefit of obtaining zero greenhouse gas emission fuel for transportation vehicles and aircrafts. In our previous work we have already demonstrated PEC cell based on $WO_3/BiVO_4$ core/shell nanorods with record water splitting efficiency approaching 8% [1]. In this work we report important findings about

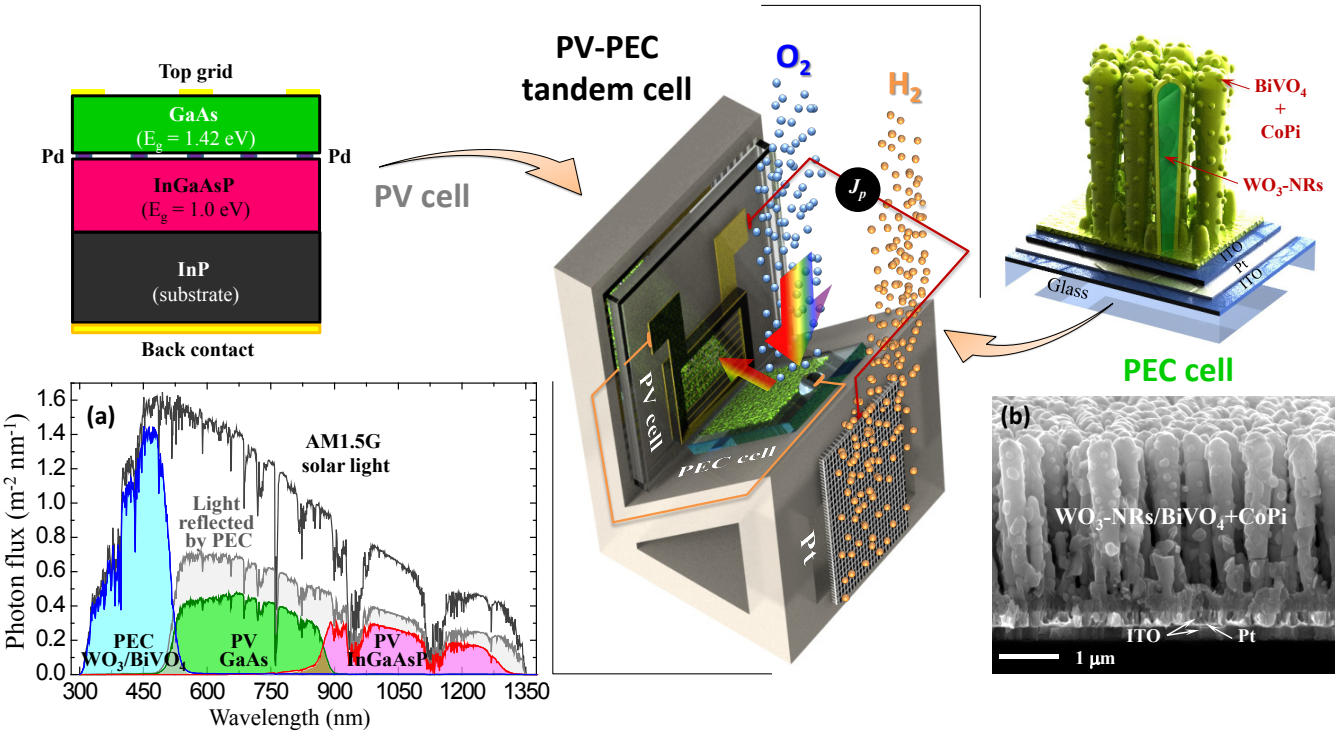

Fig. 1. Schematic illustration of the PEC-PV tandem device with the PV cell operating under reflected light from the PEC cell. The inset (a) shows utilization of the incident AM1.5G solar light by the tandem device calculated from IPCE of the PEC-PV tandem sub-cells and the reflectance spectra of the photoanode. The SEM image (b) shows a cross section of the WO_3-NRs/$BiVO_4$ PEC call.

performance of PV-PEC tandem device under combined influence of concentrated light and elevated temperature.

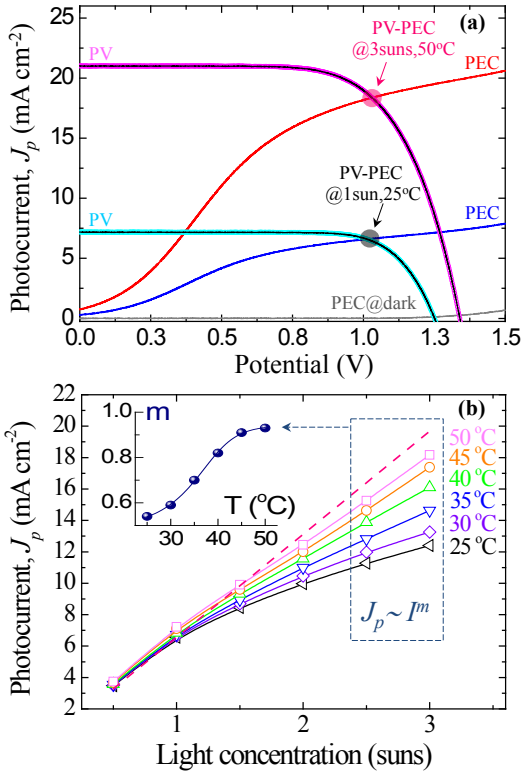

Fig. 2. (a) I-V characteristics of the PV and PEC cells and (b) combined effect of light concentration and elevated temperature on the PEC cell performance in the tandem device.

2. Experimental

The PV cell consisted of two mechanically stacked GaAs (Eg=1.42 eV) and AlGaAsP (Eg=1.0 eV) solar cells prepared by solid-state MBE followed by epitaxial lift-off (ELO) and then interconnected through aligned Pd nanoparticle arrays (Fig. 1) [2]. The solar cell was encapsulated by a glass cap and assembled on V-shape support with the PEC cell located at 45°. The PEC cell was fabricated by our original technique [1] based on combination of Glancing Angle Deposition (GLAD) of WO_3-NRs and electrodeposition of $BiVO_4$+CoPi. The performance of the PV-PEC tandem device was evaluated by following standard protocol for water splitting cells [3].

2. Results and discussion

Fig. 1a reveals balanced utilization of the AM1.5G solar light by the PV-PEC tandem device. Fig. 2a shows I-V characteristics of the PV and the PEC cells at 1 sun (25 °C) and 3 suns (50 °C) with intersection points at 6.56 mA and 18.17 mA, which correspond to the STH efficiencies of 8.1% and 7.5%, respectively. This is significantly higher than the previous record of 4.92% reported for $BiVO_4$:W,Mo/double-junction a-Si tandem device [4]. The PEC cell photocurrent shows non-linear dependence on light intensity $J_p \sim I^m$, with m ranging from 0.54 at 25 °C (recombination dominated regime) to 0.93 at 50 °C (water splitting reaction dominated regime) for $I > 2$ suns. The stability of STH conversion efficiency at 50 °C was confirmed by direct measurement of gas evolution (Fig. 3) that reveals good faradaic efficiency (> 80%). The almost linear dependence of J_p on I at elevated temperature opens a possibility for efficient water splitting under concentrated light in a PV-PEC panel module, which has enough lateral space to accommodate gas separation trenches (see Fig. 4).

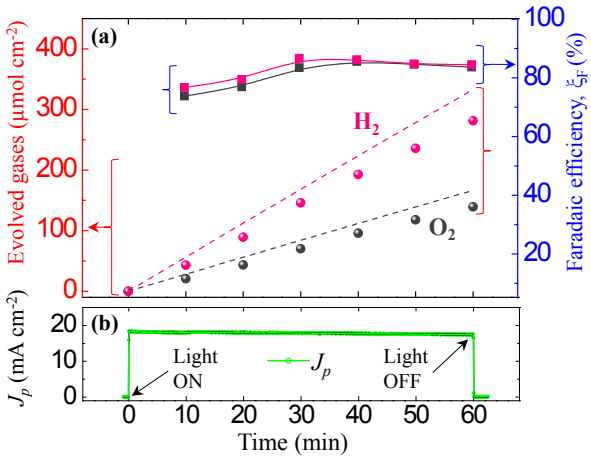

Fig. 3. (a) Experimental (circles) and theoretical (dashed lines) gas production rates with faradaic efficiencies (rectangles) for O_2 (black) and H_2 (red) measured at 3 suns and 50 °C and simultaneously recorded J_p-t profile (c).

3. Conclusions

We demonstrated efficient performance of PV-PEC GaAs/InGaAsP–WO_3-NRs/$BiVO_4$ water splitting tandem device under combined influence of concentrated light and elevated temperature and showed that infrared light can contribute to the water splitting reaction by heating the cell and thus improving the reaction kinetics.

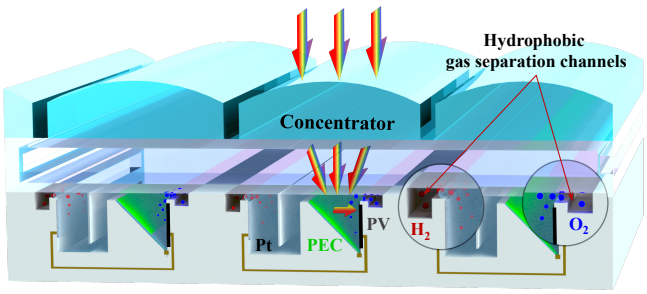

Fig. 4. Schematic illustration of water splitting module with O_2 and H_2 collecting tranches that are fitted with PEC-PV tandems, Pt counter electrodes and hemispherical light concentrators.

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