NTA2022

2nd International Conference on
Nanotechnology: Theory and Applications,
Cairo, 19 – 21 Dec., 2022

Ref. 021

Development of a microbial photo electrosynthesis system for efficient hydrogen

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KEYWORDS

Microbial photo electrosynthesis system, Photoelectrochemical cells, Hydrogen production, Microbial fuel cell, Organic wastes

SHORT SUMMARY

In this study, an integrated solar-microbial system, comprising a microbial fuel cell (MFC) fed with animal manure wastewater and a stacked titanium dioxide nanotubes (TiO_2 NTs) photoanode-based photoelectrochemical cell (PEC), was developed and tested. The hybrid system exhibited higher photocurrent and H_2 generation compared to a stand-alone PEC. The hybrid PEC–MFC system with the stacked TiO_2 NTs photoanode showed high performance for producing H_2 (i.e., 0.45 ± 0.03 m^3 H_2/m^3.day) at zero bias under illumination. This study signifies the beneficial role of MFCs to generate an electric current that can enable self-biased H_2 evolution in PECs, representing an environmentally friendly, highly efficient technology for H_2 production from renewable resources.

EXTENDED ABSTRACT

Although fossil-fuel reservoirs remain enormous to provide our society's energy demand for hundreds of years, maintaining the current status quo for providing energy would lead to an unprecedented increase in carbon dioxide (CO_2) level over the coming 30 years [1]. More importantly, in order to maintain the atmospheric CO_2 level at its current state, approximately 10 terawatts should be extracted from carbon-neutral-based sources by 2050, representing a huge challenge facing our society [2]. Photoelectrochemical water splitting is a green, sustainable technology for harnessing solar energy to generate hydrogen (H_2); however, the energy demand needed to drive this nonspontaneous reaction limits the technology's competitiveness [3]. In addition, the poor efficiency of photoanodes in photoelectrochemical cells (PECs) has been one of the factors governing the overall solar conversion efficiency of PECs [4]. Here, a novel stacking approach of n-type titanium dioxide nanotubes (TiO_2 NTs) photoanodes was proposed to improve their light-harvesting and charge transfer properties. Interestingly, the stacked photoanodes exhibited a much higher photocurrent of ~ 0.79 mA/cm^2 at 1 V (vs. SHE) than single sheet TiO_2 NTs photoanode (i.e., ~ 0.07 mA/cm^2) at the same potential, implying that TiO_2 NTs stacking approach resulted in effective light absorbance and management and much lower charge transfer resistance across the interface of photoanode and electrolyte (Figure 1). EIS analysis reveals that TiO_2 NTs stacking approach resulted in much higher overall PEC activity, which is most likely due to the effective light-harvesting and much lower charge transfer resistance across the interface of photoanode and electrolyte. Compared with the one-sheet TiO_2 NTs photoanode, which had an ABPE of 0.13% at a bias of 0.49 V (vs. Pt), the three-sheet TiO_2 NTs photoanode achieved a much higher ABPE (0.56 % at a slightly higher bias of 0.53 V (vs. Pt)) (Figure 2).

Furthermore, a self-biased, integrated solar microbial system was developed, in which a microbial fuel cell (MFC) fed with animal manure wastewater was used as a power source to drive sustainable H_2 production in a photoelectrochemical cell having stacked TiO_2 NTs photoanodes (Figure 3). The integrated system exhibited higher photocurrent and H_2 generation

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compared to a stand-alone PEC. For instance, without any external bias, the integrated system, which comprises an MFC and a three-sheet TiO_2 NTs photoanode-based PEC, generated a photocurrent of 0.44 mA/cm^2 with an H_2 production rate of 0.45 ± 0.03-m^3 H_2/m^3 day under 1 sun illumination (100 mW/cm^2), which is ~ 1.5–1.9-fold higher than other tested systems (Table 1). This study demonstrates the synergetic effect between MFCs and PECs, in which electrons recovered from waste streams biodegradation in MFCs significantly increase H_2 generation in PECs without the need for an external power source, representing an environmentally friendly, highly efficient technology for H_2 production from renewable resources.

Tables and Figures

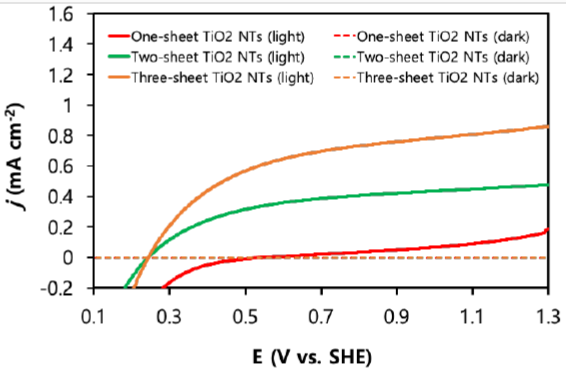

Figure 1. Linear sweep curves of photoanodes.

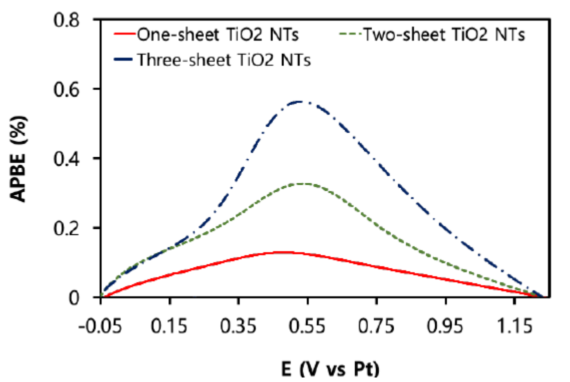

Figure 2. ABPE of photoanodes as a function of applied potential (vs. Pt).

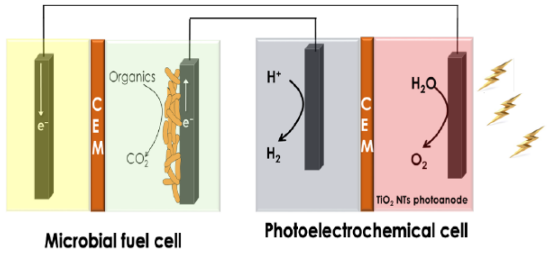

Figure 3. Schematic diagram of the integrated PEC–MFC system.

Table 1. Amperometric current production and hydrogen production rates of the integrated systems at zero bias

	Current production (mA/cm^2)	H_2 production rates (m^3 H_2/m^3.day)
One-sheet TiO_2 NTs PEC + MFC	0.26	0.23
Two-sheet TiO_2 NTs PEC + MFC	0.29	0.30
Three-sheet TiO_2 NTs PEC + MFC	0.44	0.45

Acknowledgements

This work was financially supported by the Academy of Scientific Research and Technology (ASRT), Egypt.

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