

Photoelectrocatalytic Hydrogen Production Supported by Ascorbic Acid

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Abstract

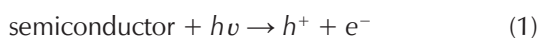
Photoelectrochemical hydrogen production combines electrochemistry and photocatalysis, resulting in sustainable hydrogen production. The process can be improved by the addition of hole scavengers, which reduce the recombination of electrons and holes, increasing the utilisation of solar radiation. Because of its low oxidation potential, ascorbic acid (AA) is an environmentally friendly and readily available hole scavenger. The commonly studied photocatalyst TiO_2 makes little utilisation of solar radiation energy due to its high energy gap of 3.2 eV. The metal sulphide SnS_2 attracts attention due to its low energy band gap of 2.2 eV, which allows the use of the visible region of the spectrum. In this work, the electrochemical characterisation of SnS_2 and TiO_2 photoanodes in NaCl solution in the presence and absence of AA was performed. The effect of AA on the photoreponse was investigated using the linear polarisation method and monitoring the open circuit potential. The results confirmed that SnS_2 and TiO_2 electrodes are photoactive, and that AA has good hole scavenging properties. Hydrogen production was performed at constant potentials of 0.6 and 1.35 V, respectively. TiO_2 exhibited higher photoactivity, thus producing more hydrogen at 0.6 V. On the other hand, at a potential of 1.35 V, most of the hydrogen produced was the result of an electrochemical reaction rather than a photoelectrochemical reaction, thus, a larger amount of hydrogen was produced with the SnS_2 electrode. The highest amount of hydrogen produced in this work was at 1.35 V for the SnS_2 electrode in an argon atmosphere and it was $0.799 \text{ ml h}^{-1} \text{ cm}^{-2}$.

Keywords

Ascorbic acid, hydrogen, hole scavenger, photoelectrochemical hydrogen production, tin(IV) sulphide, titanium(IV) oxide

1 Introduction

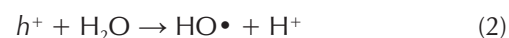
In 1972, the first report on the Fujishima-Honda effect was published, after which photoelectrochemical (PEC) generation of hydrogen and oxygen gained importance. The mentioned report showed that water splitting was possible by using light energy, with great efforts being made to develop it over time.¹ The PEC process combines electrochemistry and photocatalysis, resulting in a cost-effective approach for the sustainable production of green hydrogen. In the PEC process, the photoanode is subjected to light excitation leading to the separation of electron-hole pairs:



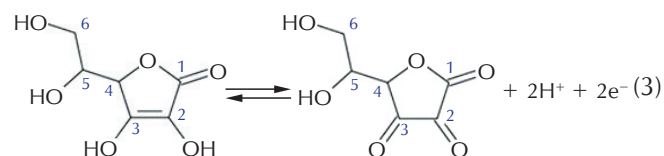
Photoinduced electrons (e^-) are continuously pulled from the anode into the external circuit and to the cathode, where hydrogen reduction occurs. The photogenerated holes (h^+) created at the anode surface oxidise water and generate oxygen. Voltage application causes the bands bending, as shown in Fig. 1, resulting in efficient charge separation.² Without voltage application, the bands are nearly flat, leading to more prominent recombination. Moreover, the process can be improved by adding agents

known as hole scavengers. Hole scavengers have a lower redox potential than oxygen,^{1,3} which reduces the minimum voltage required for hydrogen production. Well-known hole scavengers are methanol, ethylene glycol, tetraacetic acid, Na_2SO_3 and triethanolamine.⁴

The photogenerated holes at the surface of the electrode can oxidise the scavengers directly (1) or indirectly by HO^\cdot radicals generated near the electrode surface (2):



Because of its low oxidation potential, ascorbic acid is a suitable hole scavenger, and since it occurs naturally, it can be considered an environmentally friendly and readily available agent for this purpose. In the electrochemical reaction, ascorbic acid is converted into dehydroascorbic acid (3), exchanging two protons and two electrons.



However, photoelectrocatalytic degradation of ascorbic acid can also progress to a greater extent when 2,3-diketogulononic acid is formed, or even threonic and oxalic acid.⁵ In previous studies, there are only a few reports of AA being an efficient hole scavenger, but it had only been used

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in photocatalytic processes.^{6–8} There are also reports that modification of TiO₂ surface with AA resulted in an improvement of photocatalytic activity upon irradiation with visible light.^{9–11} To our knowledge, there is no report on the usage of AA as a sacrificial agent in PEC processes.

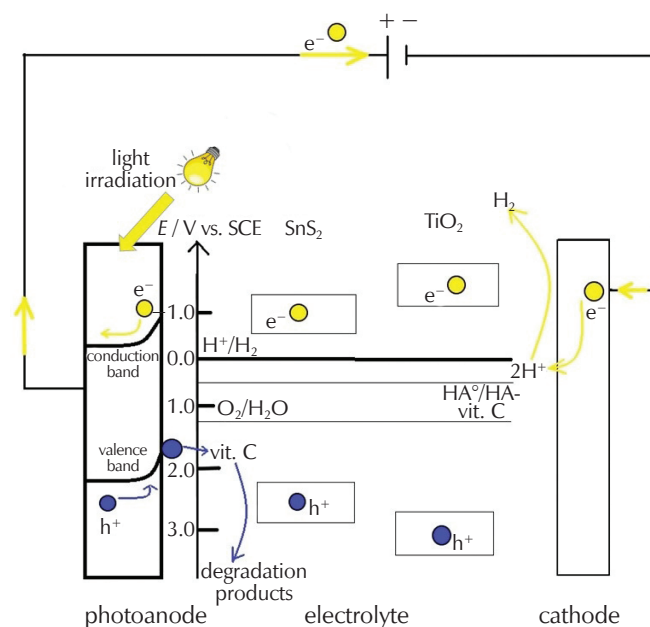


Fig. 1 – Illustration of photoelectrocatalytic hydrogen production supported by ascorbic acid

Slika 1 – Ilustracija fotoelektrokemijskog dobivanja vodika potpomognutog askorbinskom kiselinom

The most commonly studied photocatalyst is TiO₂ due to its availability, low cost, nontoxicity, high photochemical stability, and suitable band position.¹² However, two factors limit this photocatalytic material: its low ability to absorb visible light, and the rapid recombination of electron-hole pairs. Due to the energy gap of 3.2 eV, TiO₂ mainly absorbs light from the ultraviolet (UV) region of the spectrum, resulting in low utilisation of solar radiation energy.⁶ Many strategies have been proposed to overcome these limitations, such as TiO₂ dye sensitisation and TiO₂ doping with metals or non-metals (N, O, S). One of the strategies is to develop new materials that are active in the visible region (metal oxides, metal sulphides, or various heterostructures). The metal sulphide SnS₂ has attracted much attention due to its low cost and low energy band gap of 2.2 eV, which allows the absorption of photons in the visible part of the spectrum.^{13–15} In this work, the electrochemical characterisation of SnS₂ and TiO₂ photoanodes in NaCl solution in the presence and absence of AA was performed. The influence of AA on the photoresponse was studied using the linear polarisation method. To confirm the good properties, the studied system was also tested for photocatalytic hydrogen production.

2 Experimental

2.1 Active material synthesis

Aeroxide P25 TiO₂ (TiO₂-P25, Evonik, Germany) was the TiO₂ photocatalytic material used in this work. SnS₂ was prepared hydrothermally following a procedure adopted from Zhang et al.¹⁶ SnS₂ synthesis starts with dissolving the precursors (2.250 g of tin(IV) chloride and 1.205 g of thioacetamide) in a 5 % v/v solution of glacial acetic acid in ethanol (total volume of 100 ml) in a Teflon reaction vessel, constantly stirring. The Teflon reaction vessel was then transferred to a stainless-steel autoclave, and treated for 12 h at 180 °C. Letting it naturally cool to room temperature, the obtained suspension was rinsed with distilled water, centrifuged (3500 rpm for 3 min), dried in a vacuum (3 h at 60 °C), and homogenised with a porcelain pestle and mortar.

2.2 Photoanode preparation and characterisation by electrochemical methods

In this investigation, a three-electrode cell was used to characterise the photoactive materials. The cell contained a saturated calomel electrode (SCE) as a reference electrode, a platinum sheet (1 cm²) electrode as a counter electrode, and FTO glass covered with a layer of TiO₂ or SnS₂ (1.5–2 cm²) as a working electrode (Fig. 2). Measurements were performed at room temperature using a potentiostat/galvanostat (SP-150, Biologic, France), while data was recorded in the EC-lab program (V 11.33).

To prepare the working electrodes (TiO₂ electrode and SnS₂ electrode) for PEC measurements, photoactive materials (TiO₂ or SnS₂) needed to be immobilised onto FTO glass slides. This was achieved using the spin coating technique (KW-4A spin coater, Chemat Technology, USA). Prior to the coating, FTO glass slides were sonicated in acetone, EtOH, and Milli-Q water, each for 10 min, and dried at room temperature. Further, for each layer, a 200 µl aliquot of the photoactive material dispersed within the titania/silica binder was dropped onto an FTO substrate and annealed at 200 °C for 2 h in a laboratory oven (UN-55, Memmert, Germany). Further details of the procedure can be found in Sharifi et al.¹⁷

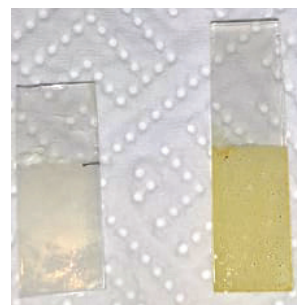


Fig. 2 – Working electrode covered with TiO₂ layer (left) and SnS₂ layer (right)

Slika 2 – Radna elektroda prekrivena TiO₂ slojem (lijevo) i SnS₂ slojem (desno)

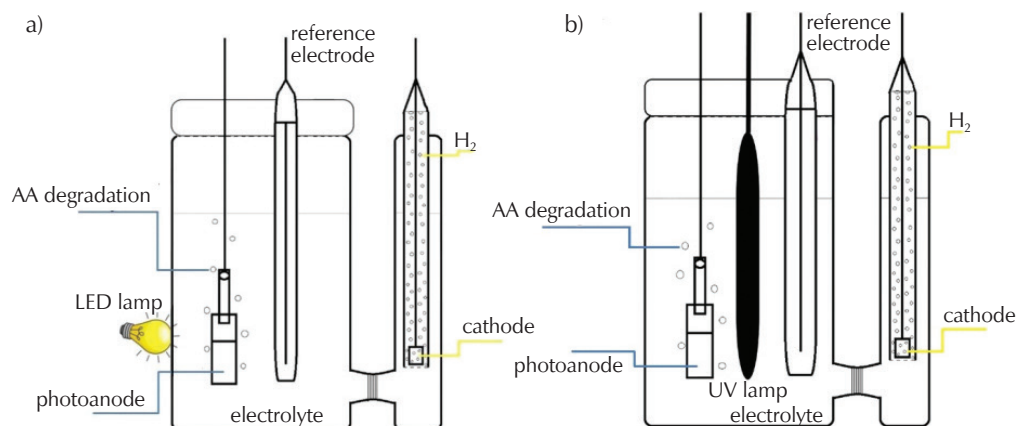


Fig. 3 – Experimental design for hydrogen production in two compartment cells containing a) SnS_2 or b) TiO_2 photoanode and platinum cathode

Slika 3 – Eksperimentalna postava za proizvodnju vodika u ćeliji s odvojenim anodnim i katodnim prostorom uz a) SnS_2 ili b) TiO_2 fotoanodu i platinsku katodu

The obtained electrodes were characterised by linear sweep voltammetry (LSV), while open-circuit potential (OCP) measurement was performed only for the SnS_2 electrode. Measurements were performed in 0.1 mol dm^{-3} NaCl solution and a solution containing 10 mmol dm^{-3} ascorbic acid dissolved in 0.1 mol dm^{-3} NaCl. The measurement was performed in dark conditions as well as under light illumination. Characterisation of TiO_2 electrodes was done under UV light (Pen-Ray 90-0019-01, 365 nm; UVP), and SnS_2 testing under LED light (COB, 50 W, 4400 lm, 6000 K)¹⁷.

All potentials in this work are reported *versus* saturated calomel electrode (SCE). Analytical-grade chemicals purchased and used in this work were NaCl (Lach-Ner, Czech Republic) and ascorbic acid (Poljo Evelin, Croatia).

2.3 Hydrogen production

The photoelectrochemical production of hydrogen using UV light and TiO_2 or LED light and SnS_2 was performed in a two-compartment cell, presented in Fig. 3. Although hydrogen evolution was the targeted process, the overall process rate depends on anode activity, and therefore in this work, anode response was monitored. Hydrogen production was carried out by the chronoamperometry method for 2 hours. The process was monitored using visual observation of the amount of hydrogen within the tube immersed in the cathodic compartment of the electrochemical cell (Fig. 3). The solution in the anodic compartment was stirred for the entire duration of the experiment using a magnetic stirrer.

The hydrogen production was carried out for 2 h at different voltage values of a) 1.35 V, and b) 0.6 V. The first voltage value was selected in the potential range where current peak was obtained, and the other voltage value was selected in the potential range where the contribution of peak current was low. Experiment at 1.35 V was also performed with argon purging for 10 min prior to the experiment in order to remove oxygen.

3 Results and discussion

3.1 Characterisation of the photoanode containing SnS_2

Fig. 4 shows the light and dark response of SnS_2 photoanode in 0.1 mol dm^{-3} NaCl solution in the presence and absence of 10 mmol dm^{-3} AA. The test was performed using the potential range from -0.5 V to $+1.5 \text{ V}$ at a scan rate of 20 mV s^{-1} .

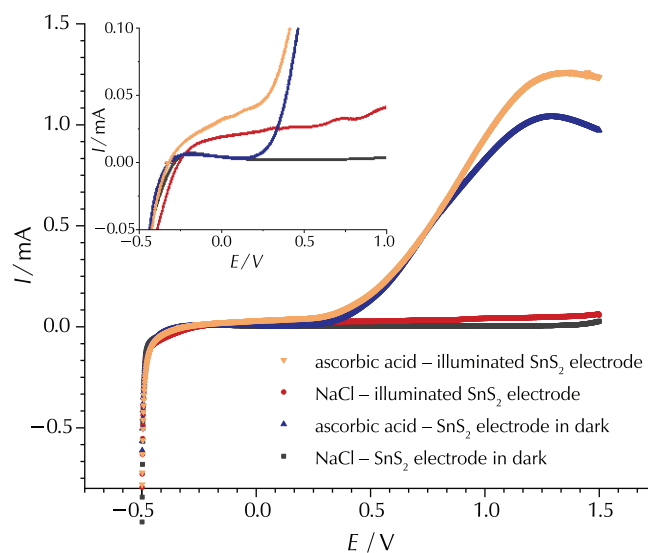


Fig. 4 – Linear sweep voltammetry responses of the SnS_2 electrode in 0.1 mol dm^{-3} NaCl solution in the presence and absence of 10 mmol dm^{-3} AA, the inset represents the enlarged part of the voltammogram

Slika 4 – Odziv voltametrijе linearne promjene potencijala za SnS_2 elektrodu u $0,1 \text{ mol dm}^{-3}$ NaCl uz prisutnost i bez prisutnosti 10 mmol dm^{-3} AA, umetak prikazuje uvećani dio voltamograma

The inset of linear sweep voltammetry responses in the NaCl solution (Fig. 4) indicates that the dark characteristic of the photoanode up to 0.25 V shows currents equal to zero, while the illuminated electrode shows a current of about 20 μA . The resulting behaviour is characteristic of photoactive materials, and the obtained current is related to the photocurrent. Furthermore, in both solutions (with the presence and absence of 10 mmol dm^{-3} AA), photocurrent increases with growing potential. This indicates a positive effect of the potential on the photocurrent response, which is a consequence of reduced electron-hole recombination.¹⁸ It is also evident that the photocurrent, recorded at lower potentials for the AA solution, was almost twice the value of the photocurrent in the NaCl solution. Therefore, it can be concluded that AA behaves as a hole scavenger, which significantly increases the photocurrent response. However, it is not completely clear whether the reaction takes place through the reaction of AA and holes or AA and radicals.^{9,11,19}

Fig. 4 also shows that the current significantly increases at potentials more positive than 0.25 V, and the current peak characteristic for the electrochemical oxidation of AA was obtained at 1.25 V. Although electrochemical oxidation is not expected when an *n*-type semiconductor electrode is used, in this investigation, it was obtained due to holes generated by an electric field.¹⁸ Similar results were also obtained for the TiO_2 electrode in the presence of antioxidants.²⁰ A higher current peak recorded for the illuminated electrode compared to the response of the dark electrode indicates photoactivity of SnS_2 in a wide potential range.

Open-circuit potential (OCP) monitoring for the SnS_2 photoanode was performed in chopped light irradiation in the AA and NaCl solutions, as shown in Fig. 5. A characteristic of an *n*-type semiconductor is a potential drop to more negative values upon illumination.^{17,18} The OCP of the

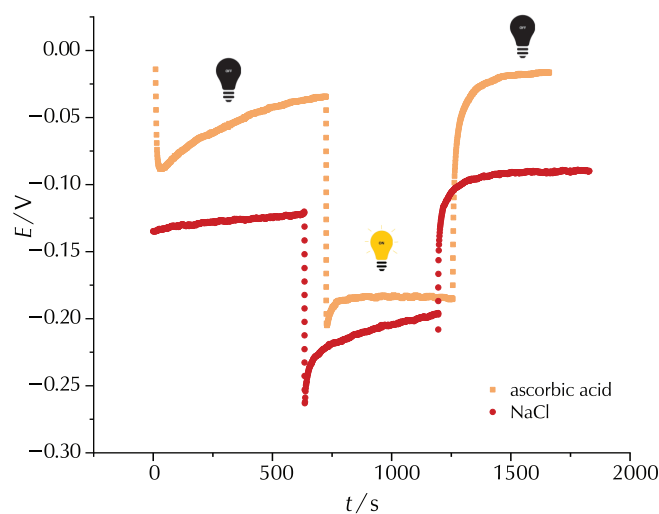


Fig. 5 – Open-circuit potential of the SnS_2 photoanode in chopped light irradiation in 0.1 mol dm^{-3} NaCl solution in the presence and absence of 10 mmol dm^{-3} AA

Slika 5 – Mjerenje potencijala otvorenog kruga za SnS_2 elektrodu u 0,1 mol dm^{-3} NaCl uz prisutnost i bez prisutnosti 10 mmol dm^{-3} AA

SnS_2 electrode in the NaCl solution exhibits a decrease of 100 mV when illuminated, while the potential of the same electrode in ascorbic acid shows a decrease of 140 mV. The obtained behaviours indicate that a higher photoactivity was obtained in the AA solution, which additionally confirms the good hole scavenging properties of AA.

3.2 Characterisation of the photoanode containing TiO_2

Fig. 6 shows a linear polarisation response of the dark and illuminated TiO_2 photoanode in a 0.1 mol dm^{-3} NaCl solution in the presence and absence of 10 mmol dm^{-3} ascorbic acid. The test was performed in the potential range from -0.5 V to $+1.2$ V at a scan rate of 20 mV s^{-1} .

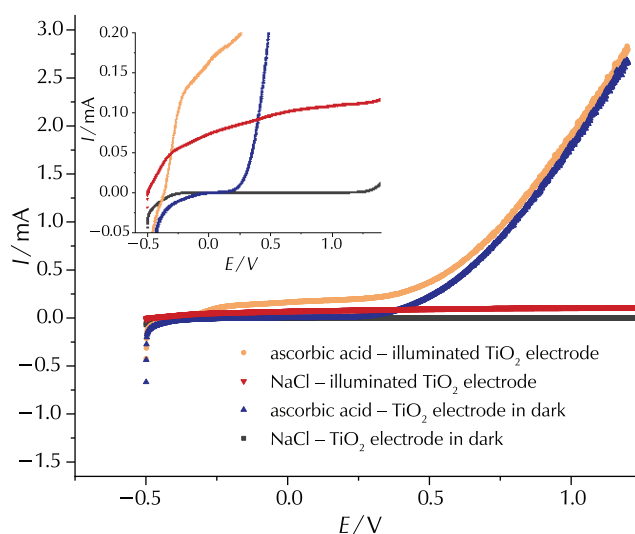


Fig. 6 – Linear sweep voltammetry responses of the TiO_2 electrode in 0.1 mol dm^{-3} NaCl solution in the presence and absence of 10 mmol dm^{-3} AA, the inset represents the enlarged part of the voltammogram

Slika 6 – Odziv voltmetrije linearne promjene potencijala za TiO_2 elektrodu u 0,1 mol dm^{-3} NaCl uz prisutnost i bez prisutnosti 10 mmol dm^{-3} AA, umetak prikazuje uvećani dio voltamograma

The inset in Fig. 6 indicates that up to 0.2 V, the dark characteristic of the photoanode (in NaCl) shows currents approximately equal to zero, while the illuminated photoanode shows a current of 75 μA at 0 V. It is also evident that the photocurrent in the NaCl solution increases with growing potential, just as in the case of the SnS_2 photoanode. With the addition of AA, the photocurrent surged to 175 μA at 0 V, proving the good hole scavenging properties of AA.

By comparing the results obtained for SnS_2 and TiO_2 (Figs. 4 and 6), it is evident that the photoactivity of TiO_2 in the presence of UV radiation is higher than the photoactivity of SnS_2 in the presence of visible radiation. However, the activity in the visible spectrum enables a more efficient utilisation of solar radiation and is, therefore, more sustainable and acceptable for a practical application.

3.3 Hydrogen production with SnS₂ and TiO₂ photoanodes

After the characterisation of the electrodes, the production of hydrogen was performed at a constant potential of 0.6 V and 1.35 V. The PEC process of hydrogen generation in the case of the SnS₂ photoanode in 10 mmol dm⁻³ AA solution was followed by monitoring current density, j , in time, t . Fig. 7 shows that the current dropped suddenly in the beginning and then gradually increased. It is also evident that the current density at 1.35 V was slightly higher when argon purging was applied before the experiment, and that the lowest current value was recorded at a potential of 0.6 V. The similar experiment was carried out for the TiO₂ photoanode (Fig. 8), and the same trend was obtained.

The currents at 1.35 V are mainly the result of an electrochemical reaction, as evident from the responses registered during the linear polarisation experiment (Figs. 4 and 6). In this case, the photocurrent contribution to the overall current response was small. For this reason, similar current values were recorded for TiO₂ and SnS₂ electrodes (1.7–1.8 mA and 1.75–2 mA) (Figs. 7 and 8). At a lower potential value (0.6 V), the photocurrent contribution was more significant, and therefore the difference between the TiO₂ and SnS₂ response was more pronounced. For the SnS₂ electrode, the current of 0.3 mA was recorded, while for the TiO₂ electrode the current of 0.5 mA was recorded (Figs. 7 and 8). The obtained result indicates better photoactivity of TiO₂ compared to SnS₂, which is in accordance with linear sweep voltammetry results (Figs. 4 and 6).

Additionally, Figs. 7 and 8 show that the current at the very beginning of the process rises suddenly and then falls. These currents are most likely a characteristic of electrochemical double-layer charging. The continuous current increase, registered after the initial drop, could be an indication of: 1) a mechanical decomposition of the electrode, which

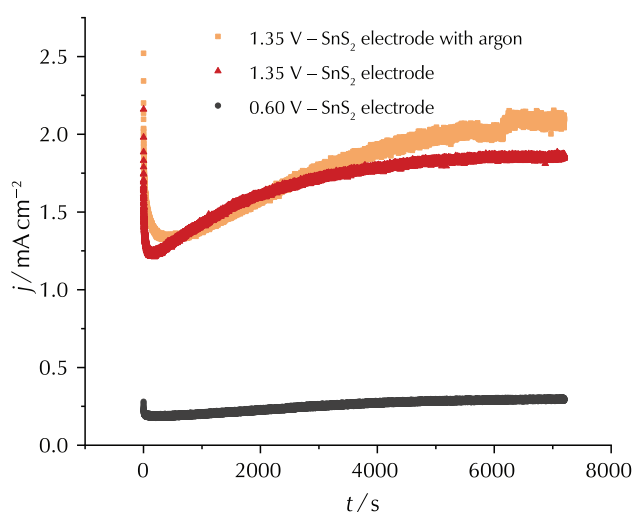


Fig. 7 – Chronoamperometry response recorded during PEC hydrogen generation with the SnS₂ photoanode in 10 mmol dm⁻³ AA solution in 0.1 mol dm⁻³ NaCl

Slika 7 – Kronoamperometrijski odziv zabilježen tijekom dobivanja vodika u sustavu sa SnS₂ fotoanodom u otopini 10 mmol dm⁻³ AA u 0.1 mol dm⁻³ NaCl

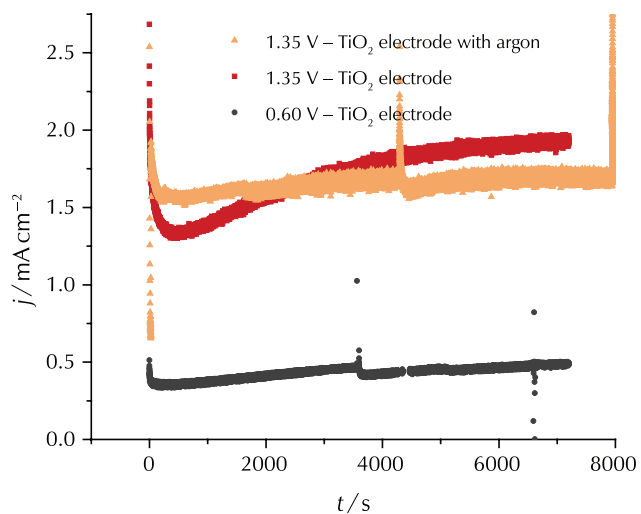


Fig. 8 – Chronoamperometry response recorded during PEC hydrogen generation with the TiO₂ photoanode in 10 mmol dm⁻³ AA solution in 0.1 mol dm⁻³ NaCl

Slika 8 – Kronoamperometrijski odziv zabilježen tijekom dobivanja vodika u sustavu s TiO₂ fotoanodom u otopini 10 mmol dm⁻³ AA u 0,1 mol dm⁻³ NaCl

leads to an increase in the surface of the electrode, or 2) a decomposition products reaction.²¹ In order to determine what exactly affected the current increase (Figs. 7 and 8), additional analysis of the electrode surface and products generated within the solution should be carried out.

Table 1 – Results related to hydrogen production with the SnS₂ electrode

Tablica 1 – Rezultati koji se odnose na dobivanje vodika uz SnS₂ elektrodu

Electrode area /cm ² Površina elektrode/cm ²	Voltage/V Napon/V	Argon Argon	Hydrogen evolution rate/ml h ⁻¹ cm ⁻² Brzina razvijanja vodika /ml h ⁻¹ cm ⁻²
2.31	1.35	No	0.725
1.52	0.60	No	0.016
1.44	1.35	Yes	0.799

Table 2 – Results related to hydrogen production with the TiO₂ electrode

Tablica 2 – Rezultati koji se odnose na dobivanje vodika uz TiO₂ elektrodu

Electrode area /cm ² Površina elektrode/cm ²	Voltage/V Napon/V	Argon Argon	Hydrogen evolution rate/ml h ⁻¹ cm ⁻² Brzina razvijanja vodika /ml h ⁻¹ cm ⁻²
1.98	1.35	No	0.707
1.53	0.60	No	0.098
1.98	1.35	Yes	0.783

Tables 1 and 2 show the amounts of produced hydrogen under the investigated conditions. The largest volume of hydrogen was produced in an argon atmosphere at a potential of 1.35 V. Under these conditions, $0.799 \text{ ml h}^{-1} \text{ cm}^{-2}$ hydrogen was produced using the SnS_2 photoanode, and $0.783 \text{ ml h}^{-1} \text{ cm}^{-2}$ hydrogen was produced using the TiO_2 photoanode. A slightly smaller volume was generated at a potential of 1.35 V in an oxygen atmosphere, $0.725 \text{ ml h}^{-1} \text{ cm}^{-2}$ for SnS_2 photoanode, and $0.707 \text{ ml h}^{-1} \text{ cm}^{-2}$ for TiO_2 photoanode. When hydrogen is produced in an oxygen atmosphere,²² in addition to the hydrogen reaction, the oxygen reduction reaction also takes place. Therefore, more hydrogen will be produced in an argon atmosphere²³ where the oxygen reduction is prevented.

By comparing the amount of hydrogen, it is evident that, at 1.35 V, a similar amount of hydrogen was produced with both the TiO_2 and SnS_2 photoanodes. This supports the previous conclusion that the current related to the electrochemical oxidation of AA is dominant over the photocurrent at 1.35 V. Hence, the better photoactivity of TiO_2 did not result in a higher amount of hydrogen. At a potential of 0.6 V, the volume of hydrogen is higher for the TiO_2 electrode, which is in accordance with the current values recorded during the PEC process (Figs. 7 and 8). Therefore, it is obvious that, at 0.6 V, the photocurrent was dominant over electrochemical reaction.

In previous studies, $0.65\text{--}0.89 \text{ ml h}^{-1} \text{ cm}^{-2}$ hydrogen in 1 mol dm^{-3} KOH solution at 1.62 V was produced using a W-doped electrode and a Cr-doped TiO_2 electrode with a RuO_2 layer.²² Using a TiO_2/WO_3 electrode in 0.5 mol dm^{-3} NaClO_4 solution with ethanol as a hole scavenger and at a potential from 0.27 to 1.37 V, the recorded amount of hydrogen ranged from 0.24 to $0.72 \text{ ml h}^{-1} \text{ cm}^{-2}$.²³ The hydrogen obtained by photocatalysis in 1 mol dm^{-3} solution of $(\text{NH}_4)_2\text{SO}_3$ was 86.6 to $155.2 \text{ } \mu\text{mol h}^{-1}$ (2.08 to 3.72 ml h^{-1})/ 50 mg WP/CdS photocatalyst.²⁵ Comparing the aforementioned results with the results from this investigation, it can be concluded that hydrogen volumes obtained at the higher potentials are equal to or greater than the values previously reported.^{23–25} However, hydrogen volumes generated at lower potentials are slightly lower than those reported in the literature. It can be concluded that the application of AA as a hole scavenger in the PEC process investigated in this work was successful and shows potential for practical application.

4 Conclusion

In this work, the electrochemical characterisation of SnS_2 and TiO_2 electrodes confirmed a good photoactivity. By using an AA solution, the LSV photocurrent response significantly increased, confirming that AA behaves as a good hole scavenger. OCP monitoring also proved the good hole scavenging properties of AA. LSV indicated that the photoactivity of TiO_2 under the UV lamp was higher than the

photoactivity of SnS_2 under the LED light. Although TiO_2 photoanode showed better results, its disadvantage is the requirement of UV light. Consequently, SnS_2 appears to be the more suitable photoanode due to efficient solar radiation harvesting.

The photocatalytic hydrogen production was performed at a constant potential of 0.6 V and 1.35 V to prove the good applicable properties of the investigated system. Besides a photocatalytic reaction, an electrochemical reaction also took place in the range of investigated potentials, and contributed to the produced hydrogen quantity. At a 1.35 V potential, most of the produced hydrogen was the result of the electrochemical reaction, so it is not surprising that a larger quantity of hydrogen volume was provided with the SnS_2 electrode. At a lower potential value of 0.60 V, the contribution of the photocurrent was more significant, making the difference between the TiO_2 and SnS_2 responses more pronounced.

The higher amount of hydrogen, for both electrodes, was produced at a potential of 1.35 V in an argon atmosphere where competitive oxygen reduction reaction was prevented. It can be concluded that the application of AA as a hole scavenger in the PEC process is promising for practical applications.

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List of abbreviations and symbols Popis kratica i simbola

- E – potential, V
– potencijal, V
- j – current density, mA cm^{-2}
– gustoća struje, mA cm^{-2}
- t – time, s
– vrijeme, s
- I – electric current, A
– jakost električne struje, A
- AA – ascorbic acid
– askorbinska kiselina
- FTO – fluorine-doped tin oxide
– fluorom dopiran kositrov oksid
- PEC – photoelectrochemical
– fotoelektrokemijsko
- SCE – saturated calomel electrode
– zasićena kalomel elektroda

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SAŽETAK

Fotoelektrokemijsko dobivanje vodika potpomognuto askorbinskom kiselinom

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Fotoelektrokemijski procesi kombiniraju primjenu napona i fotokatalizu, što može rezultirati održivom proizvodnjom vodika. Proces se može poboljšati dodatkom sredstva koje reagira sa šupljina, čime se smanjuje rekombinacija elektrona i šupljina. Askorbinska kiselina (AA) smatra se ekološki i ekonomski prihvatljivim sredstvom pogodnim zbog svojeg niskog oksidacijskog potencijala. Najčešće upotrebljavani fotokatalizator, TiO_2 , u fotokatalitičkom procesu slabo iskorištava sunčevu svjetlost zbog velikog energetskog procjepa od 3,2 eV. Metalni sulfid, SnS_2 , privlači pažnju zbog malog energetskog procjepa od 2,2 eV, koji omogućava uporabu vidljivog dijela spektra. Elektrokemijska karakterizacija SnS_2 i TiO_2 fotoanoda provedena je u otopini NaCl uz prisutnost i bez prisutnosti AA. Utjecaj AA na fotostruje praćen je metodom linearne promjene potencijala i mjerenjem potencijala otvorenog kruga. Rezultati su potvrdili da su SnS_2 i TiO_2 elektrode fotoaktivne te da je AA pogodna za smanjenje rekombinacije elektrona i šupljina. Da bi se potvrdila dobra svojstva istraživanog sustava, provela se reakcija dobivanja vodika pri konstantnim potencijalima od 0,6 i 1,35 V. Pri potencijalu od 0,6 V više vodika je dobiveno uz TiO_2 elektrodu, jer ona pokazuje veću fotoaktivnost. Pri 1,35 V većina proizvedenog vodika bila je rezultat elektrokemijske reakcije te je veći volumen vodika dobiven uz SnS_2 elektrodu. Najveća količina vodika u ovom radu, $0,799 \text{ ml h}^{-1} \text{ cm}^{-2}$, proizvedena je pri 1,35 V uz SnS_2 elektrodu kao fotoanodu u atmosferi argona.

Ključne riječi

Askorbinska kiselina, vodik, sredstvo za smanjenje rekombinacije, fotoelektrokemijski proces, kositrov(IV) sulfid, titanijev(IV) oksid

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