

Research on Dye-Sensitized Solar Cell Coupling System of Water-Splitting for Hydrogen Production

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Abstract-Using dye-sensitized solar cells coupled water-splitting electrode to produce hydrogen, compared with the traditional photoelectrolytic cell water-splitting energy consumption is much smaller. Because the entire photoelectric system is exposed to the air, so it solves the problem of the photoelectric cell's water-splitting electrode corrosion seriously. It use three tandem dye-sensitized photovoltaic cells as a source of power, the open circuit voltage of photoelectric unit is 1.547V, shows the feasibility of using dye-sensitized photovoltaic cell decomposition of water to produce hydrogen. However, the maximum power point voltage of the photoelectric unit is 0.902V, and the photoelectric system still needs to be further optimized because of the system of water-splitting running at 1.3-1.4V photovoltaic.

Keyword- Dye-sensitized Solar Cell; Coupling; System of Water-splitting for Hydrogen Production

I. INTRODUCTION

The traditional dye-sensitized solar cell water-splitting systems are done directly at water-splitting photoanode of TiO₂ [1], Pt as the counter electrode, the two electrodes immersed in the electrolyte. When TiO₂ anode is exposed to light, the Pt electrode generates the hydrogen. Because of energy shortage of TiO₂ anode, it is needed to add bias to the electrolysis of water, so the electrolytic efficiency of this method has not improved. For the spectral sensitivity of the photoelectric material is not the best choice, and the whole decomposition process is in the solution thoroughly, its electrochemical corrosion is also more seriously. Taking into account all these factors [2-6], it improved the traditional dye-sensitized photovoltaic cells of water-splitting system, using dye-sensitized photovoltaic cells coupled with water-splitting electrode, two units integrated directly to establish a system of water-splitting for hydrogen production. Modulation photoelectric unit materials, size, intrinsic properties of dye-sensitized solar cell and modulating of electrolysis unit material, size, electrolytes, etc., can make a photoelectric unit and electrolysis unit well matched, including the level/energy match, spectral matching, power matching etc., can maximize the utilization efficiency of solar energy, which can be built into an integrated efficiency self-coupling solar water-splitting system for hydrogen production [7].

II. EXPERIMENTAL

A. Materials and Apparatus

TiO₂ nanoparticles (P25), butyl titanate, iodine, potassium iodide, DMF, polyglycol M-2000, KOH, Eosin Y were purchased from the Shanghai Chemical Agent Ltd., China (Analytical purity grade). All reagents were used without further treatment. Conducting glass plates (FTO glass, Fluorine doped tin oxide over-layer, sheet resistance 15Ω/cm², purchased from Hartford Glass Co. This was used as a substrate for precipitation of a TiO₂ porous film and was cut into rectangles with a size of 2cm×1.5cm). Ruthenium oxide coated titanium electrode was made by our team [8]. The main apparatus includes a stabilized power supply Xe/Hg arc lamp (CHF-XM-500W, Changtuo Scientific Ltd, Beijing, China).

B. Production of Dye-sensitized Solar Cell

The anode of dye-sensitized solar cell is films made by sol-gel and powder method. A certain amount of nano-TiO₂ powder is adding in TiO₂ sol [9] and adds a certain amount of polyethylene glycol, sufficiently stirred, ultrasonic dispersion to obtain TiO₂ slurry. The film was made with glass bars for proper amount of TiO₂ slurry dripping on FTO conductive glass, drying at room temperature and then annealing in a muffle. After hydrolysis of the intermediate product suitable high-temperature annealing was completely decomposed, residual organic matter can be completely removed, and finally completely dehydrated, only closely integrated with the substrate of titanium dioxide films. The counter electrode was prepared by electroplating method on FTO conductive glass with pt. Eosin Y as sensitizer. The use of KI and I₂ DMF solution are regarded as the electrolyte.

C. Experimental Device

Fig. 1 is the experimental device. It's an integrated efficiency self-coupling solar water-splitting system for hydrogen production [10]. Three dye-sensitized solar cells as the photoelectric unit in series are connected between each cell with

palladium sheet. The anode used in the electrolytic unit is a ruthenium oxide coated titanium electrode, a platinum plate as a cathode and 1mol/L KOH solution as the electrolytic solution. Adjusting the parameters of the two photoelectric units and the electrolytic unit to achieve maximum conversion efficiency.

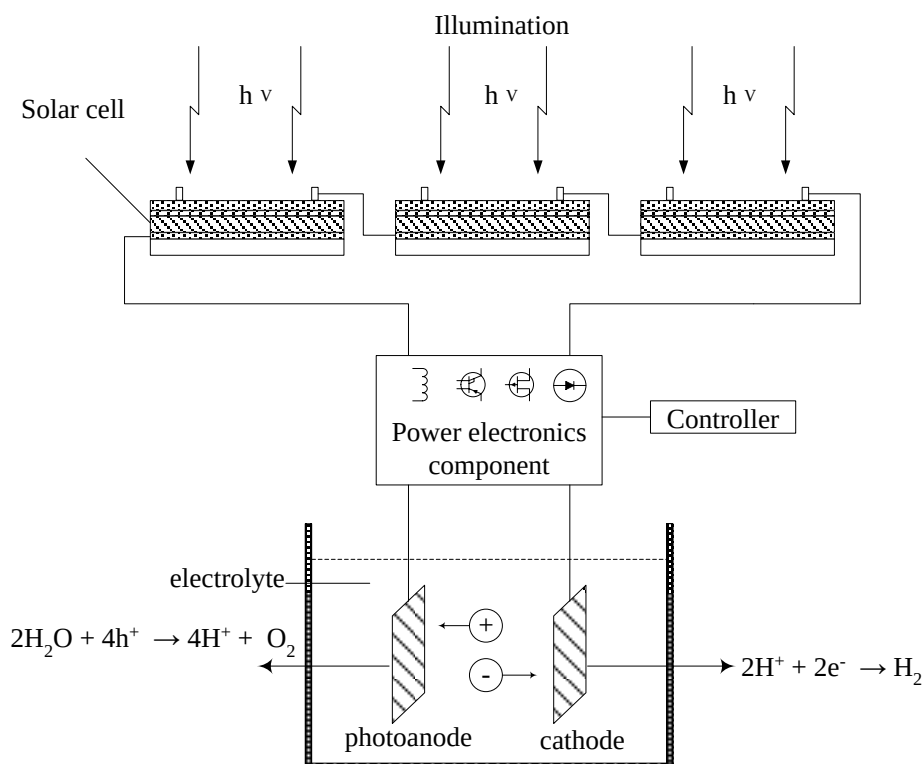


Fig. 1 Integrated efficiency self-coupling solar water-splitting system for hydrogen production

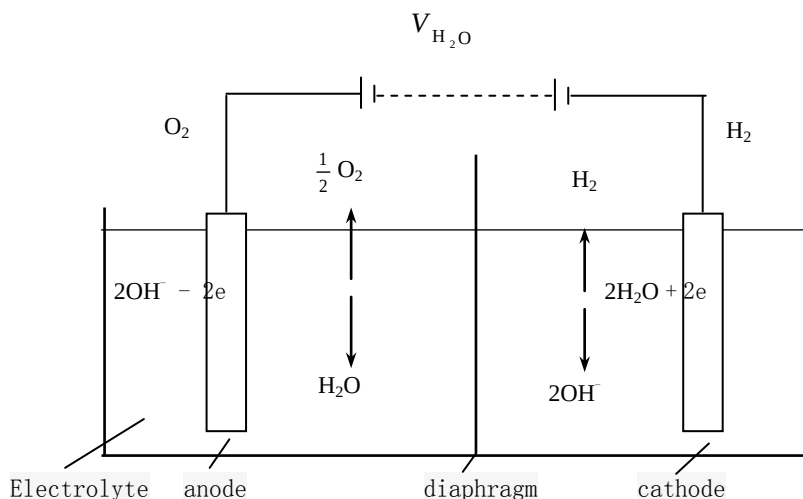
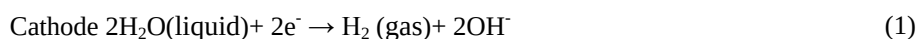
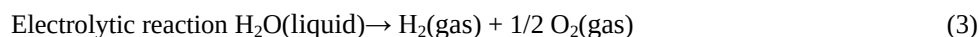
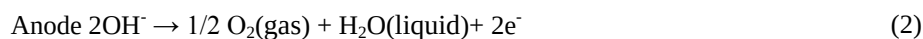


Fig. 2 Schematic diagram of the electrode reaction of water electrolysis process

Fig. 2 is a schematic diagram of the electrode reaction of water electrolysis process. The main composition of electrolytic cell includes a power supply, electrolyzer, electrolyte, cathode, anode and diaphragm. The diaphragm consists mainly of asbestos, the separation from the gas and the two electrodes are mainly playing the role of electrocatalysis decomposition of water, to produce hydrogen and oxygen. At the cathode, two water molecules are decomposed into two hydrogen ions and two hydroxide ions, hydrogen ions are generated electron hydrogen atom, and further generate a hydrogen molecule. Hydroxide ions in the electric field force between the anode and cathode through the porous diaphragm to reach the anode, the anode loses two electrons to form a water molecule and 1/2 oxygen molecule. Anode and cathode reaction is shown as in formula (1) and formula (2) respectively:





D. Test Method for the Performance of the System

The photoelectric unit of the test system is three dye-sensitized solar cells in series, the electrolysis unit is ruthenium oxide coated titanium electrode and platinum electrode, the light source is xenon lamp, corrected by AM solar energy conversion efficiency of a solar simulator, the IV determination of characteristics is determined by programmed potentiostat.

III. RESULTS AND DISCUSSION

The maximum power point voltage of single dye-sensitized solar cell is 0.466V, the fill factor is 0.425, the efficiency of light electricity is 0.42%. Photoelectric unit of water-splitting system using three dye-sensitized photovoltaic cell series system, only when the open circuit voltage of the photoelectric unit is far greater than the electrolysis voltage can the electrolysis of water, to provide maximum efficiency is only working voltage is close to the maximum power point voltage. In this system, the light first enters the wide band gap, most of high energy photons are absorbed in here and low energy photons are through. Wide band gap photons are absorbed ($h\nu > E_{\text{GW}}$) to excite e^-/h^+ electron pair, PN junction or Schottky junction to suppress the charge recombination, promote the charge into the small band gap layer, in the narrow bandgap by long wavelength ($h\nu > E_{\text{Gs}}$) light stimulated further.

Fig. 3 shows the use of simulation of light source, the I-V curve of three dye-sensitized photovoltaic cell system. Under the light, the photoelectric system for generating the open circuit voltage 1.547V, far more than the thermodynamic voltage electrolysis reaction, this energy is sufficient to effectively promote the photoelectric response.

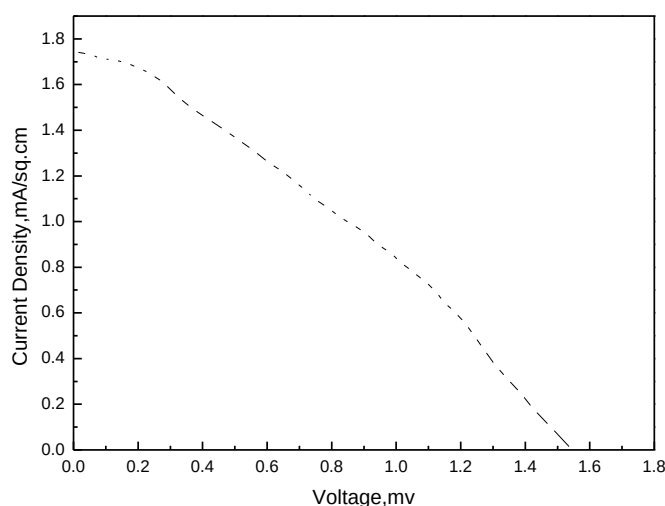


Fig. 3 I-V curve of three dye-sensitized solar cells in series

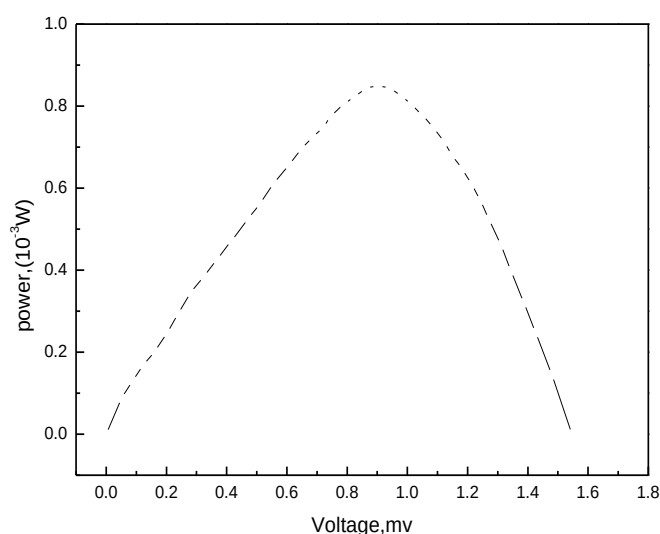


Fig. 4 P-V curves of three dye-sensitized solar cells in series

From Fig. 3 and Fig. 4 can know that the open circuit voltage is 1.547V, the short-circuit photocurrent is 1.745 mA, the maximum power is 0.851mW, the maximum power point voltage is 0.902V, it can calculate the fill factor is 0.302 by formula (4) and photoelectric conversion efficiency is 0.37% by formula (5).

$$ff = \frac{I_{mp} V_{mp}}{I_{sc} V_{oc}} \quad (4)$$

$$\eta = \frac{ff V_{oc} I_{sc}}{P_{in}} \times 100\% \quad (5)$$

Three series of dye-sensitized photovoltaic cell system under simulated light irradiation, resulting in the open circuit voltage of 1.547V, which exceeds the voltage of the electrolysis reaction thermodynamic theory, can promote the photoelectric response, but since the fill factor of the photoelectric unit is low, resulting in the maximum power point voltage of the photoelectric unit in 0.902V, the decomposition voltage of water is not well matched, to be more optimal space at in the experiment, there are two ways, one of which is further optimization of single-cell system, and the second is to make dye-sensitized photovoltaic cell series-parallel combined.

IV. CONCLUSIONS

The experiments demonstrate the feasibility of using dye-sensitized solar cell as the power supply to the decomposition of water. Adjusting the parameters of the photoelectric unit and electrolysis unit to make them well matched can maximize solar energy efficiency, which can build into a highly efficient integrated self-coupling solar water-splitting system.

- In low over-potential or high temperature conditions, it can make the $V_{H_2O}(T)$ close to or less than $E^0_{H_2O}$, which will greatly improve the efficiency of the electrolysis of water;
- Modulating the two electrodes in the electrolytic cell, making the electrode material a small overpotential and using of solar thermal heating temperature effect can both reduce $V_{H_2O}(T)$ value decomposition of water system and improve η electrolysis.

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