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Round-the-Clock Continuous Charging of the Fuel Cell of an Electric Vehicle for its Non-stop Movement

M. Shoikhedbrod*

Abstract

The development of a hydrogen and oxygen photoelectrolyzer-generator, powered by the light energy, of an electric vehicle's interior lamp, which allows the fuel cell of an electric vehicle to be charged around the clock and continuously for its non-stop movement, is an important step in replacing conventional transport with an economical electric vehicle. The article presents a developed photoelectrolyzer-generator, powered by the light energy of an electric car interior lamp, producing pure hydrogen and oxygen, which charges the fuel cell of an electric car around the clock, leading it to non-stop operation. Horizontally located on the bottom of developed photoelectrolyzer-generator electrodes, separated from each other by a thin membrane, made from fire hose material, the gap between which is regulated by a special device in the developed photoelectrolyzer-generator, permit during the process of the electrolysis of ordinary water, continuously supplied to the photoelectrolyzer-generator, to produce pure gases of hydrogen and oxygen. Round-the-clock production of oxygen and hydrogen in the photoelectrolyzer-generator and therefore round-the-clock continuous charging of the fuel cell of an electric vehicle for its non-stop movement is ensured by using lamp as an electrical load for the photoelectrolyzer-generator, including an LED with a daylight charger, which allows, in an energy-saving way, during the operation of the photoelectrolyzer-generator, to alternately illuminate the photoelectrolyzer-generator with the electric vehicle interior lamp, and when the electric vehicle interior lamp is turned off, by an LED, powered by the battery charged during operation of the electric vehicle interior lamp.

Keywords: Electric vehicle; Electrolysis hydrogen and oxygen bubbles; Water electrolysis; Hydrogen and oxygen generator; Electrolysis base; Membrane from a fire hose

INTRODUCTION

Using a photoelectrochemical cell that is directly powered by solar energy is one of the best ways to produce clean hydrogen and oxygen [1-4]. Under the action of four photons of light, a silicon semiconductor of a photoelectrochemical cell with an attached mesh anode submerged in an aqueous electrolyte solution "loses" four electrons, leaving four positively charged "holes" that "attract" four electrons from four hydroxyl anions (4OH-) of the adjacent dissociated into the hydrogen cation (H^+) and hydroxyl anion (OH^-) of water: $H_2O \leftrightarrow H^+ + OH^-$, which forms two water molecules and an oxygen molecule:$4OH^- - 4e^- = 2H_2O + O_2\uparrow$.

The oxygen molecule floats from a silicon semiconductor with an attached anode to the free surface of the water in the form of an oxygen gas bubble.

Two positively charged hydrogen cations $2H^+$ of a neighboring dissociated aqueous solution, having reached the negatively charged cathode, return two electrons to it, while being neutralized into two

***Author for Correspondence**
M. Shoikhedbrod
E-mail: michaelshoikhedbrod@bell.net

Active Director, Electromagnetic Impulse Inc., 21 Four Winds Drive, Unit 12, North York, Ontario M3J 1K7, Canada

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separate hydrogen atoms, which, being in the Free State, combine with each other, forming a gaseous hydrogen molecule ($2H^+ + 2e^- \rightarrow H_2\uparrow$), which in an aqueous electrolyte solution takes the form of an electrolysis bubble, floats from the cathode to the free surface of the aqueous electrolyte solution.

Four electrons "knocked out" from the silicon semiconductor with attached mesh anode and two electrons returned to the cathode by the two hydrogen cations form a direct electric current, directed from the positively charged silicon semiconductor with attached anode to the negatively charged cathode. Figure 1 illustrates the operation of a photoelectrochemical cell under the influence of light.

The article presents a developed photoelectrolyzer-generator, powered by the light energy of an electric car interior lamp, producing pure hydrogen and oxygen, which charges the fuel cell of an electric car around the clock, leading it to non-stop operation.

Horizontally located on the bottom of developed photoelectrolyzer-generator electrodes, separated from each other by a thin membrane, made from fire hose material, the gap between which is regulated by a special device in the developed photoelectrolyzer-generator, permit during the process of the electrolysis of ordinary water, continuously supplied to the photoelectrolyzer-generator, to produce pure gases of hydrogen and oxygen.

Round-the-clock production of oxygen and hydrogen in the photoelectrolyzer-generator and therefore round-the-clock continuous charging of the fuel cell of an electric vehicle for its non-stop movement is ensured by using vehicle lamp as an electrical load for the photoelectrolyzer-generator, including an LED with a daylight charger, which allows, in an energy-saving way, during the operation of the photoelectrolyzer-generator, to alternately illuminate the photoelectrolyzer-generator with the electric vehicle interior lamp, and when the electric vehicle interior lamp is turned off, by an LED, powered by the battery charged during operation of the electric vehicle interior lamp.

MATERIALS

Ordinary water was used as a source for continuously operations of developed photoelectrolyzer-generator in a closed cycle: tank with ordinary water + photoelectrolyzer-generator: hydrogen and oxygen gases + electric vehicle fuel cell charging and electric vehicle engine operation + generated water + tank with ordinary water.

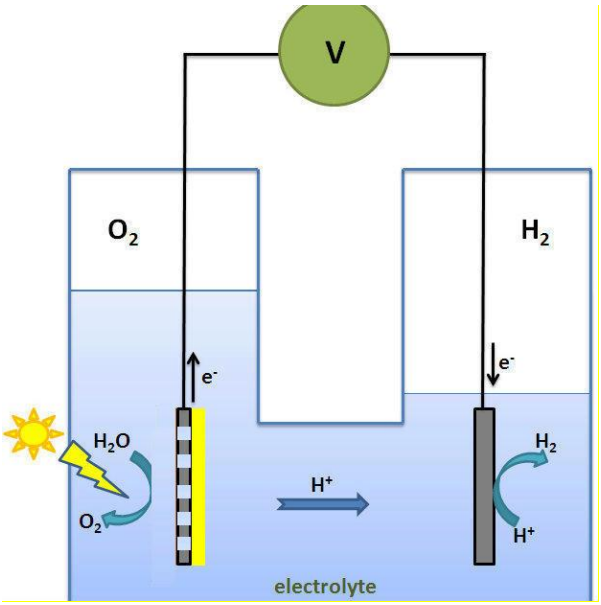

Figure 1. The operation of a photoelectrochemical cell under the influence of light.

Method and Developed Devices

A photoelectrochemical cell is a silicon semiconductor with an attached mesh anode and a cathode, connected by an electrical circuit for the flow of direct electric current, generated by the action of light on the silicon semiconductor with an attached mesh anode, immersed in an aqueous electrolyte solution.

In the ***N-type*** layer [5-8] of silicon with phosphorus added to it acquires the property of being freed from free electrons in the outer orbit to bring the outer orbit in a normal state, therefore a silicon semiconductor with an attached mesh anode, immersed in an aqueous electrolyte solution, excited by four photons of light, "loses" four electrons, leaving behind four positively charged vacant "holes" that attract four electrons from four hydroxyl anions ($4OH^-$) of neighboring water dissociated into a hydrogen cation (H^+) and a hydroxyl anion (OH^-):

$$H_2O \leftrightarrow H^+ + OH^-, \quad (1)$$

which leads to the formation of two water molecules and an oxygen molecule, which in water takes the form of an oxygen electrolysis bubble, floating from the surface of the cathode to the free surface of the water:

$$4OH^- - 4e^- = 2H_2O + O_2\uparrow \quad (2)$$

Two positively charged hydrogen cations $2H^+$ of a neighboring dissociated water, having reached the negatively charged cathode return two electrons to it, neutralizing into two separate hydrogen atoms, which, being in the Free State, combine with each other, form a gaseous hydrogen molecule, which in water takes the form of an electrolysis bubble of hydrogen, floating from the surface of the cathode to the free surface of the water.

$$2H^+ + 2e^- \rightarrow H_2\uparrow \quad (3)$$

Four electrons "knocked out" from a silicon semiconductor with an attached mesh anode, passing through the ***N-type layer*** of a silicon semiconductor with an attached mesh anode, along the electrical circuit to the cathode and two electrons returned to the cathode from two hydrogen cations, make it a negative pole, and the anode, which loses electrons, becomes a positive pole generate a constant electric current, directed from a silicon semiconductor with an attached mesh anode to the cathode (Figure 2).

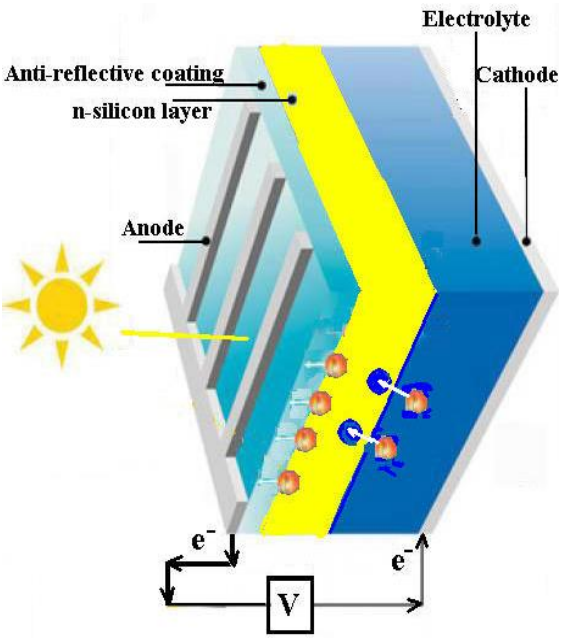

Figure 2. The silicon layer n-type operations under the action of light.

The author in [9, 10] established that the size and intensity of the formation of negatively charged electrolysis hydrogen bubbles and positively charged oxygen bubbles can be controlled by increasing the electrical potential of the electrodes, making the intensively formed bubbles as small as required by the technological process.

The above conclusion served as the basis for the development of a photoelectrolyzer generator. An important feature of the developed photoelectrolyzer-generator is the horizontal arrangement of electrodes in the lower part of the photoelectrolyzer-generator, separated from each other by a thin membrane, made from fire hose material, the gap between which is regulated by a special device, allowing during the electrolysis of ordinary water continuously supplied to the photoelectrolyzer-generator, obtain pure gases of hydrogen and oxygen.

A thin membrane of fireman's material, placed between a silicon semiconductor with attached mesh anode and cathode, prevents the penetration of electrolysis oxygen bubbles, resulting from attraction of the four hydroxyl anions of surrounding the dissociated water, donating four electrons to the four positively charged "holes", formed by the impact of four photons of light on a silicon semiconductor with attached mesh anode, resulting in the formation of two water molecules and an oxygen molecule, released in the form of an oxygen gas bubble that floats from the surface of the silicon semiconductor with attached mesh anode to the top of a photoelectrolyzer - generator and is released as a foam of gas oxygen from the anode zone of the photoelectrolyzer-generator through the oxygen outlet tube.

As a result of electrolysis, electrolysis hydrogen bubbles are intensively formed in the cathode zone of the photoelectrolyzer-generator and are removed in the form of foam of hydrogen gas from the cathode zone of the photoelectrolyzer-generator through the hydrogen tube.

The horizontal arrangement of electrodes in the lower part of the photoelectrolyzer-generator, separated from each other by a thin membrane, made from fire hose material, the gap between which is regulated by a special device, in contrast to photoelectrochemical cells existing today, where the electrodes are located vertically, allows during the process of electrolysis of ordinary water, continuously supplied to the photoelectrolyzer-generator, to produce pure hydrogen and oxygen gases quickly and economically.

The horizontal arrangement of the electrodes in the lower portion of the photoelectrolyzer-generator, where the electrodes are located in the horizontal direction and occupy the entire bottom of the electroflotation apparatus, as in all electroflotation devices, sharply reduces the cross-sectional area and lengthens the conductive layer between the electrodes. This is in contrast to the vertical electrode arrangement that occurs in photoelectrochemical cells with an aqueous electrolyte solution (Figure 1). The efficiency of a photoelectrochemical cell or photoelectrolyzer is determined by the intensity of gas evolution in them.

Gas evolution (***M)*** from the electrode over time (***t***), according to Faraday's law, is calculated, using the following formula:

$$M = jigSt \tag{4}$$

where j - the electrochemical equivalent of gas (for hydrogen $j = 1.0\ 10^{-7}$ *кg/* ($A \cdot s$); for oxygen $j = 8.29\ 10^{-8}$ *кg/* ($A \cdot s$)); i - the current density, A/m^2; $g = 90\%, 95\%$ - current output (the ratio of actual gas mass transfer to the theoretical calculated in percentage terms); S - the cross-sectional square of the conductive layer between the electrodes, m^2.

A sharp decrease of the cross-sectional area and a sharp increase of the length of the conductive layer between the electrodes in accordance with (4) leads to a sharp decrease of the gas evolution of hydrogen and oxygen in the photoelectrochemical cell and, as a consequence, to a sharp decrease of the efficiency of the photoelectrochemical cell.

For compensation of the reduction of gas evolution of hydrogen and oxygen in an aqueous electrolyte solution, an expensive electrolyte (for example, ***NaOH***) is used, the concentration of which in the solution is ***40%***, which leads to a sharp increase of the energy consumption of the photoelectrochemical cell, reaching ***4.5 kWh/m^3*** for hydrogen production.

A significant advantage of the developed photoelectrolyzer-generator over existing electroflotation devices is the absence of electrodes in the electrolysis base, which use dense meshes with small cells, causing high currents of the order of ***100 amperes*** at low voltages (***20-30V***).

The explanation of this significant advantage is as follows.

If we consider ***i*** – the process current density as ***I/S***, where ***I*** is the direct current of the process, then equation (4) will take the following form:

$$M = jIgt \tag{5}$$

From equation (5) it is clear that the mass of gas, released on the electrode during time ***t***, is directly proportional to the magnitude of the direct current and does not depend on the area of the electrode. However, in accordance with Ohm's law, the value of the direct current of the process is directly proportional to the electrode voltage (***U***) and inversely proportional to the resistance of the interelectrode medium (***R***):

$$I = U/R \tag{6}$$

The resistance of inter electrode medium (***R***), in turn, depends on the inter electrode gap (***L***) and the cross-sectional square of the conductive layer between the electrodes (***S***) as follows:

$$R = \rho\frac{L}{S} \tag{7}$$

Where ρ – resistivity of the inter electrode medium.

Substituting (7) to (6) will obtain:

$$I = (US/\rho L) \tag{8}$$

Thus, from (8) it can be seen that the reduction of the cross-sectional square of conductive layer between the electrodes of photoelectrochemical cell (***S***), in our case, a change of the shape of the electrode (silicon semiconductor with attached mesh anode with large cells) can be compensated by increasing the voltage (***U***) on the electrodes to maintain the same efficiency of the photoelectrochemical cell (previous gas evolution - ***M***).

Increasing the voltage across the electrodes guarantees maximum gas evolution of vigorously generated hydrogen bubbles at the cathode and oxygen at a silicon semiconductor with a connected mesh anode, while also maintaining the efficiency of the photoelectrolyzer-generator, as previously mentioned. In addition to drastically reducing the cross-sectional area and the length of the conductive layer between the electrodes, the electrodes are arranged vertically, which leads to a sharp decrease of gas evolution and the intensity of the formation of electrolysis bubbles of hydrogen and oxygen, but also prevents the formation and rapid removal of electrolysis bubbles of hydrogen and oxygen through hydrogen and oxygen tubes accordingly.

Due to the Archimedes force, which acts strictly vertically with respect to the cathode or anode, electrolysis hydrogen or oxygen bubbles that form on the entire horizontal surface of the electrode or anode and break away from the electrode surface rush upward and are removed from the photoelectrolyzer-generator as bubbles of hydrogen gas or bubbles of oxygen through the hydrogen or oxygen tubes. The Archimedes force, which acts tangentially to the cathode or anode and prevents the

separation of hydrogen bubbles from the cathode or oxygen bubbles from the anode, causes the resulting bubbles of hydrogen and oxygen in vertically positioned electrodes to float up near the cathode and anode, forming a narrow flow.

24-hour and continuous production of hydrogen and oxygen in the photoelectrolysis generator is ensured by using an LED with a daylight charger as a useful electrical load, illuminating the silicon semiconductor with an attached mesh anode at night until the morning and by continuously filling the photoelectrolysis generator with water.

LED with daylight charger as a useful electrical load is a lighting lamp for lighting the anode at night, including light-emitting diode, a control board, a photoresistor and a protective glass (Figure 3).

The principle schema of the lamp control board is shown in Figure 4. The current, generated by the photoelectrolyzer - generator, through diode **D1** charges the battery (**A**). The positive potential, applied to the base through resistor **R1** "holds" transistor **T1** in the off state and **LED D2** does not light up.

With a significant decrease of illumination of the anode, the transistor opens (due to a decrease in the positive potential, applied to the base) and connects **LED D2** to the battery. The **LED** starts to light up, illuminating the anode.

Diode **D1** prevents the battery from discharging through the photoelectrolyzer-generator. With the onset of dawn, the positive voltage coming from the "+" output of the photoelectrolyzer-generator to the base "closes" transistor **T1** and ***LED D2*** stops lighting, and the battery begins to charge.

Figure 5 shows the round-the-clock continuous operation of the developed photoelectrolyzer-generator, which generates and removes hydrogen and oxygen bubbles separately through the corresponding tubes.

Structurally, the photoelectrolyzer-generator has an inlet for water continuously supplied to the photoelectrolyzer-generator, and two separate outlet tubes for removing hydrogen and oxygen bubbles.

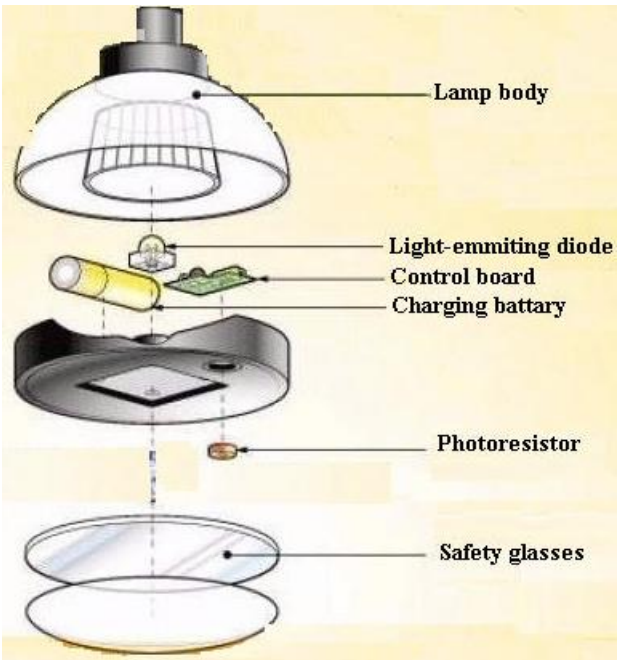

Figure 3. A lighting lamp as photoelectrolyzer-generator useful electrical load for lighting the anode at night.

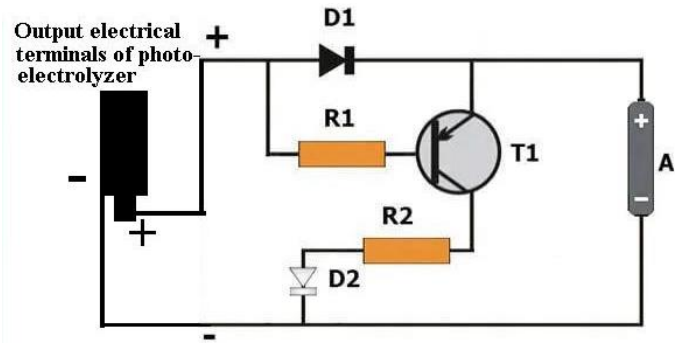

Figure 4. The principle schema of the lamp control board.

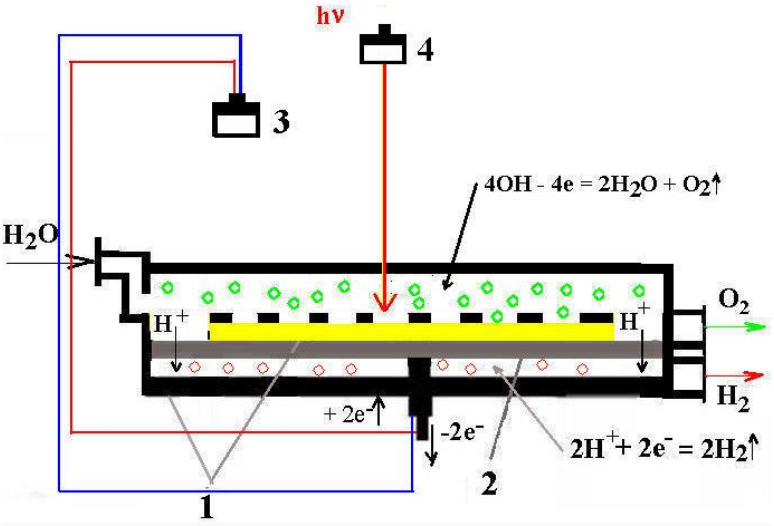

Figure 5. The round-the-clock continuous operation of the developed photoelectrolyzer-generator, which generates and removes hydrogen and oxygen bubbles separately through the corresponding tubes.

The main element of the developed photoelectrolyzer-generator is the design of the electrolysis base (1), which includes electrodes located horizontally at the bottom of the developed photoelectrolyzer-generator, separated from each other by a thin membrane made of fire hose material, the gap between which is regulated by a special device. A silicon semiconductor with a mesh anode attached to it, generating electrolysis oxygen bubbles due to the impact of four photons of light of vehicle interior lamp (4) on the silicon semiconductor with an attached mesh anode, located above the cathode made of baked graphite.

At the base of the photoelectrolyzer-generator is where the cathode is mounted. There is a membrane, composed of fire hose material (2), positioned between the cathode and the silicon semiconductor with mesh anode attached. This membrane stops the oxygen bubbles from penetrating into the cathode area and allows hydrogen cations to enter the cathode to form microdispersed electrolytic hydrogen bubbles intensely. Ordinary water continuously enters to the photoelectrolyzer-generator.

The developed photoelectrolyzer-generator works as follows:

In a photoelectrolyzer-generator, a silicon semiconductor with an attached mesh anode, immersed in a water and excited by four photons of light from vehicle interior lamp , “loses” four electrons, leaving four positively charged “holes” that attract four electrons from four hydroxyl anions ($4OH^-$) of the adjacent dissociated into the hydrogen cation (H^+) and hydroxyl anion (OH^-) of water: $H_2O \leftrightarrow H^+ + OH^-$, resulting in the formation of two water molecules and an oxygen molecule: $4OH^- - 4e^- = 2H_2O + O_2\uparrow$.

The oxygen molecule, in the form of a bubble of oxygen gas, floats from the silicon semiconductor with the attached anode to the top of the photoelectrolyzer-generator and is discharged through the oxygen tube to the oxygen cathode of the fuel cell of the electric car.

Two positively charged hydrogen cations $2H^+$ of a neighboring dissociated water, having reached the negatively charged cathode, return two electrons to it, neutralizing into two separate hydrogen atoms, being in a Free State, connecting to each other, forming a gaseous hydrogen molecule ($2H^+ + 2e^- \rightarrow H_2 \uparrow$), which in a water takes the form of an electrolysis bubble, floating from the cathode surface to the membrane, and is discharged through the hydrogen tube to the hydrogen anode of the fuel cell of the electric car.

Four electrons "knocked out" from a silicon semiconductor with attached mesh anode and two electrons returned to the cathode from two hydrogen cations generate a constant electric current, directed from a positively charged silicon semiconductor with attached anode to the negatively charged cathode.

Round-the-clock and continuous production of hydrogen and oxygen in the photoelectrolyzer-generator, and therefore round-the-clock continuous charging of the fuel cell of an electric vehicle for its non-stop movement, is ensured by using a lamp (4), including an LED as a useful electrical load with a charger charging under the light of the electric vehicle cabin lamp, which illuminates the silicon semiconductor with an attached mesh anode at night until the morning and constantly filling the photoelectrolyzer-generator with water.

Figure 6 shows the full cycle of round-the-clock and continuous production of hydrogen and oxygen and charging of the fuel cell of an electric vehicle by the developed photoelectrolyzer-generator by: photoelectrolysis of ordinary water continuously supplied from the tank; continuous charging of the fuel cell of an electric vehicle produced by oxygen and hydrogen; the use of a lamp that includes an LED with a charger, which is charged by the light of an electric vehicle interior lamp, as a useful electrical load and the return of water vapor released during charging of the fuel cell to a tank with ordinary water.

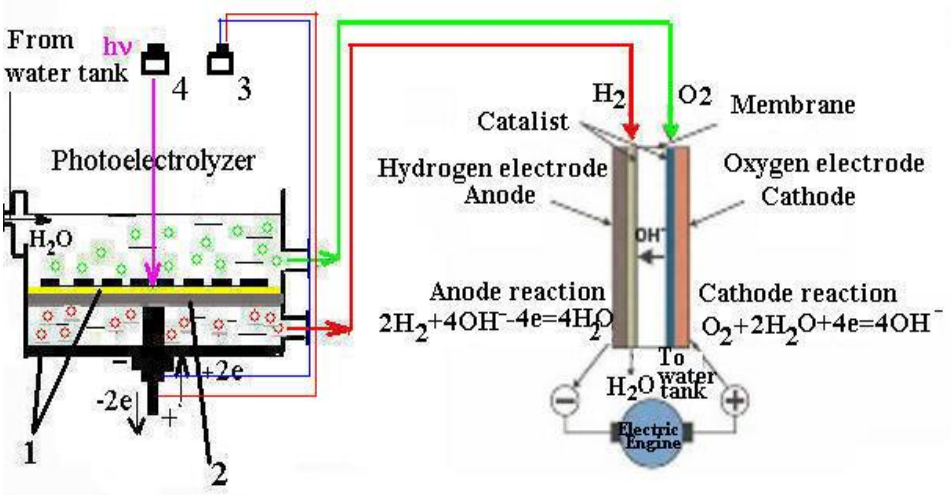

Figure 6. Full cycle of round-the-clock and continuous work of the developed photoelectrolyzer-generator.

Every electrode in an automobile fuel cell has a coating of catalyst covering it. An oxygen molecule reacts with two water molecules in the hydrogen electrode anode, losing four electrons in the process and releasing four positive charges on the oxygen cathode. Four OH- anions then react with two hydrogen molecules in the hydrogen electrode anode, creating a negative potential on the other engine contact (at

the hydrogen electrode), and forming four water molecules (water vapor), which return to the tank with regular water, completing the cycle: container regular water reservoir including photoelectrolyzer-generator: creation of hydrogen and oxygen gas during photoelectrolysis + continuous fuel cell charging and engine running of the electric vehicle + water vapor + regular water tank:

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \rightarrow 2H_2 + 4OH^- - 4e^- \rightarrow 4H_2O^- \quad (9)$$

RESULTS

Round-the-clock and continuous production of pure hydrogen and oxygen for the purpose of round-the-clock and continuous charging of the fuel cell of an electric vehicle by photoelectrolysis of ordinary water on a specially developed photoelectrolyzer-generator showed an advantage over other existing photoelectrochemical cells due to the electrodes, located horizontally at the bottom of the developed photoelectrolyzer-generator, separated from each other by a thin membrane, made from fire hose material, the gap between which is regulated by a special mechanism and using a lamp that includes an LED with a charger, which is charged by the light of an electric vehicle interior lamp, as a useful the photoelectrolyzer-generator electrical load.

Producing ***1 m^3*** of pure hydrogen and oxygen by a photoelectrolyzer-generator with a cross-sectional area of conducted water of ***1 m^2*** required a voltage at the electrodes of ***100 V***, causing a constant electric current of ***4 A***.

Thus, the developed photoelectrolyzer used ***400W*** of light energy from electric vehicle interior lamp to produce ***1m^3*** of pure hydrogen and oxygen.

The energy efficiency of the developed photoelectrolyzer-generator for the production of ***1 m^3*** of pure hydrogen and oxygen in percent was calculated using the following formula:

Output energy = ***(Input energy)*** x ***100***.

The output energy in our case is ***400 watts***, spent by the developed photoelectrolyzer-generator to obtain ***1 m^3*** of pure hydrogen and oxygen.

Energy consumption (***Input energy***) in our case is the power that the lamp gives, about ***1300 watts*** per square meter (***m^2***).

Thus, the energy efficiency of the developed photoelectrolyzer-generator when producing ***1 m^3*** of pure hydrogen or oxygen in percentage will be (***400 W***/***1300 W***) x ***100*** = ***30.77%***, that is, quite high.

Tests have shown that round-the-clock and continuous generation of hydrogen and oxygen by photoelectrolysis of ordinary water in a specially designed photoelectrolyzer-generator allows the round-the-clock and continuous charging of the fuel cell of an electric vehicle engine, which leads to non-stop operation of the electric vehicle engine. Continuous generation of hydrogen or oxygen by photoelectrolysis of ordinary water in a specially designed photoelectrolyzer-generator is carried out in an environmentally closed cycle: ordinary water tank + photoelectrolyzer-generator: round-the-clock and continuous production of gaseous hydrogen and oxygen in the process of photoelectrolysis + charging of the fuel cell and operation of the electric vehicle engine + water steam + regular water tank.

CONCLUSION

Thus, with the use of a specially created photoelectrolyzer-generator, light-energy photoelectrolysis of regular water can be used to power an electric vehicle engine continuously and efficiently around-the-clock. This allows the engine's fuel to be continuously and efficiently charged.

The developed photoelectrolyzer-generator, operating in an environmentally closed cycle, produces pure hydrogen or oxygen continuously and, in turn, charges the fuel cell of an electric vehicle

continuously. This is accomplished through photoelectrolysis of ordinary water, which is carried out horizontally at the bottom of the photoelectrolyzer-generator by electrodes (silicon semiconductor with an attached grid anode with large cells and a burnt graphite cathode, located one above the other), separated from each other by a thin membrane.

Made from fire hose material, the gap between which is regulated by a special device and a lamp, including an LED with a charger charged from light of an electric vehicle interior lamp, illuminating a silicon semiconductor with an attached grid anode with large cells when the electric vehicle interior lamp is turned off, used as a useful electrical load of a photoelectrolyzer-generator.

Tests have shown that the round-the-clock and continuous generation of hydrogen and oxygen by photoelectrolysis of ordinary water in a specially designed photoelectrolyzer-generator, powered by the light energy of the interior lamp of an electric vehicle, allows for round-the-clock and continuous charging of the fuel cell of the electric vehicle engine, which leads to non-stop operation of the electric vehicle engine without the need for autonomous recharging.

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