Green Laser Enhances More Proton Conductivity Compared to Blue Laser: Water Electrolysis

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Abstract

The effect of external electromagnetic field in enhancing the proton conductivity via water electrolysis is investigated. Diode-pumped solid state laser (DPSS) operating at second harmonic generation is employed as a source of light that carried external electric field and magnetic field. The electrolysis chamber is irradiated by green laser (532 nm) and blue laser (450 nm) for comparison. The present study reports the proton conductivity (PC) which is hydrogen production is induced by the water splitting initiated by the electric field from power supply and sustained by the external electric field which carried by electromagnetic wave (laser) attributed to breaking the intermolecular force of the water molecules and hydrogen bonding. A comparison in measuring rate of hydrogen production by electrolysis with aided between blue laser and green laser irradiation is reported. Hydrogen production rate can be enhanced by overcoming the residual electric field of the electrolysis system. Thus, green laser contributes extra electric field to overcome the weak residual electric field caused by the polarizability property of water which the rate of hydrogen production (HP) higher compared to HP by aiding the blue laser irradiation which are 0.4573 mL/min-1 and 0.2718 mL/min-1 respectively.

Keywords: proton conductivity, hydrogen, water splitting, and laser irradiation.

1. Introduction

Manipulating dynamics of molecules with electric fields and photo energy has long been a sought-in order to understand the phenomena involve in the hydrogen production. Several researchers focused on producing hydrogen production by electrochemical [1], photochemical splitting [2] and photo-catalytic membrane reactors [3]. Zou et al. [4] has proposed a direct splitting of water into stoichiometric amounts of oxygen and hydrogen under visible light irradiation with a quantum yield of about 0.66% hydrogen production efficiency [4]. Besides, ultraviolet UV light source is also being studied for photolysis process [5]. A UV light at 351/364 nm from a focused argon laser was employed as a source of light. This technique proposed allows a quantitative examination of the actual gas evolution rate during photo-electrochemical water splitting, independent of current measurements [6]. In addition, a research about the hydrogen generation by laser irradiation of carbon powder in water has been made by Akimoto et al. [7]. A 532 nm green laser is employed; and was found that a highly carbonized charcoal (Bincho-tan) is effectively works for electrodes-less electrolysis. Green laser is also used as a light source during water electrolysis and known as green laser electrolysis [8].
Moreover, by considering the water electrolysis process efficiency, the inexpensive cost, and environmentally clean technology, therefore in this study, electrolytic production of hydrogen is carried out with a dilute distilled water solution and sodium chloride as ionic substances to allow the current flows supported by the electric field supplied by power supply and in this particular experiment, the significance of laser irradiation to electrolysis was identified by comparing two types of diode pump solid state (DPSS) lasers. The use of an electric field to generate large water splitting is of considerable interest in a number of practical applications. In order to know the factors leading to such high proton conductivity, variation of electric field tests in water were carried out in electrolysis by adding the laser light irradiation.

In the present work, when electromagnetic (EM) wave was applied into the conventional water electrolysis which carry external electric field utilized to induce proton conductivity and support conduction charges to respective electrodes, we discovered that the rate of hydrogen production in electrolysis anticipated by green laser irradiation (0.4573 mL/min$^{-1}$) higher than blue laser irradiation (0.2718 mL/min$^{-1}$).

2. Experimental

We used experimental setup of laser electrolysis is illustrated as in Figure 1. In this study, pyrex beaker with volume 500 mL was used as a chamber. It was filled with aqueous 0.02 M sodium chloride NaCl as an ionic substance to allow the current to flow in the chamber. Two graphite electrodes were vertical hold and kept at a constant distance of 5 cm. The electrode was connected through a copper wire to the power supply which supply electric field in order to initiate the water splitting. About 6 cm$^2$ of molybdenum sheet is connected in series to the electrode to act as sacrifice agent. A magnetic stirrer was used to homogenize the water through electrolysis process. The applied cell voltage is fixed to 20 V for each experiment. A diode pump solid-state laser DPSSL was employed as a visible light source in the water electrolysis. DPSSLs are solid-state lasers made by pumping a solid gain medium such as a ruby or a neodymium-doped YAG crystal, with a laser diode. The DPSS laser model DPG-2000 operated in continuous (CW) mode with second harmonic generation at 532 nm and 450 nm. The output power fixed in the range 120 mW. The beam diameter spot is approximately 5 mm. Originally, green laser beam is irradiates horizontally to the electrolysis cell from cathode to anode direction. The distance of laser head to the beaker (electrolysis cell) is approximately 45 cm. Next, the blue laser beam is irradiates as same condition with previous system. Hydrogen gas collected at cathode terminal is measured in every two minutes. A digital thermometer was used to measure the temperature changes during the progress of hydrogen evolution. The interaction time to measure the HP was studied in the range of 0 to 10 minutes.
3. Results and Discussions

It is well understood that to allow the current to flow in the electrolysis chamber, ionic substances had to be used and in this work, sodium chloride (NaCl) was used. To ensure this parameter, several quantity of NaCl was tested to comprehend the effectiveness in water electrolysis process.
Figure 2. Current flows in the system against the weight of sodium chloride used

The experimental result shows that weight of NaCl had significant effect on the current flow. Figure 2 represents the highest current flow in the system was 1.2 µA with the 1 g of NaCl while when small amount of NaCl, 0.2 g was used, the measured current flow was lowest which was only 0.3 µA. Meanwhile, when 0.4 gram was used, the current flow rise up to 0.8 µA and for 0.6 g dan 0.8 g, the current flow for this two quantity of NaCl is slightly the same which were 1 µA. This indications that current flows at different quantity of NaCl and the current increases linearly with the ionic substances and as the concentration of NaCl became higher, electrolyte conductivity increased, tends to accelerate water splitting. Therefore, the PC leads toward hydrogen production also increases.

To initiate the water electrolysis, the electric field from power supply must be applied to the system. The linear relationship indicated that HP relies on the electric field from the power supply as shown in Figure 3.
Figure 3. Rate of Hydrogen Production at different voltage

The rate of HP in this manner was found to be as 0.30383 mL/min V. Increase in HP with respect to time was interrelated to the accumulative voltage from power supply and this indicated that electrical current play an advantageous factor for promoting electrolysis. Electric field could split the water molecule and that process may induced the energy in the form of heat thus the molecules vibrate. If the vibrations were strong enough, the molecules broke of the van der Waals' forces that hold them together. In the case of water, these forces were hydrogen bonding. So, enough energy supplied into electrolyte encouraged forces between the molecules to break. Creating an electric potential through water caused positive ions, including the inherent hydrogen ions H\textsubscript{3}O\textsuperscript{+}, to move towards the negative electrode (cathode) and negative ions, including the inherent hydroxide ions OH\textsuperscript{-}, to move towards the positive electrode (anode). At sufficient potential difference, this caused electrolysis with hydrogen gas produced at the cathode. Chaplin [9] reported that from the current flowing in that system, the amount of product formed (the gases) can be calculated directly. It was proved that higher voltage electric field capable to raise the water activity by breaking the hydrogen bonding. This left the hydrogen atoms on average positively charged and the oxygen atom negatively charged, and the resulting structure was known as an electric dipole.

However, the water molecules had a dielectric constant of 80. This means 80% of water molecule will be polarized when electrolyte was provided with power supply. Such polarization generate another field but in opposite direction from the main. The substruction of the electric field was referred as residue electric field (REF) [8]. This was the left over field used to transport the charges or ions in the electrolysis process. It was also the main weakness of the electrolysis process and had to be modified for developing the efficiency of water electrolysis. A further possibility of water splitting would be by applying external electric field effect to support the weakness of the residue of electrical field. For improving productivity and electrical efficiency, we altered the electrolysis system by appending the external electric field from light source. According to the previous work, Norah et. al, discovered that green laser 532 nm could enhance the hydrogen production [8]. Furthermore, laser energy has potential to prevent the
recombination process therefore when the laser is illuminated in the water, it will increase the kinetic energies of $\text{H}_2$ and $\text{O}_2$ and dissociate the water molecule thus the present of electrical power source can boost the dissociation process in the water [10].

![Graph showing rate of HP with respect to time based on light irradiation sources during water electrolysis]

**Figure 4.** Rate of HP with respect to time based on light irradiation sources during water electrolysis

Figure 4 shows the HP at different laser irradiation source (using blue and green light laser) during water electrolysis at 120 mW. The graph shows similar trend of hydrogen gas yield during electrolysis that is linearly increased with respect to time. Hydrogen yield is higher while employing the green laser (532 nm) as the source of laser electrolysis. The hydrogen rate for green laser electrolysis is about 0.4573 mL min$^{-1}$ and 0.2718 mL min$^{-1}$ for blue laser. The wavelength of blue light laser is 450 nm, its photon energy is partially absorbed by the water molecule. This will cause the electric field carried by blue light laser become lower compared to green laser. This situation can be proved by the Figure 5 which presented that while the intensity of blue light with wavelength 450 nm passing through beaker and when it passed through water and beaker were in the range 3000 a.u. which indicated that the intensity was low when passed through the medium. In contrast, the intensity of the laser 532 nm at direct irradiation was high, which was 17694 a.u.

![Graph showing intensity of laser irradiation 532 nm passing through three different medium]

**Figure 5.** The intensity of laser irradiation 532 nm passing through three different medium.
Furthermore, the intensity of light determine the energy consumption in water electrolysis to make the process into electrical effective. The effect of an electric field on water seems to be stronger. The presence of this external electric field is important to enhance the residual electric field of the electrolysis cell [8].

Through this work, it showed that the presence of green light laser during water electrolysis showed significant increase of HP compared to the blue laser. Owing to the characteristics of green laser energy that is not absorbed into the water molecules, the amplitude of electric field of green laser is not reducing. This is will gives an optimum forces cause by electric field of the laser to the electron charges.

4. Conclusion

The experimental results revealed that the HP is very dependent on the efficiency of the current flow in the conventional water electrolysis. HP from the electrolysis is increased by the variables: voltage, NaCl and green laser irradiation (532nm) which is more effective compared to the blue laser irradiation (450 nm). Thus, in this study, it is proved that higher voltage electric field and sodium chloride (NaCl) capable to raise the water activity by breaking the hydrogen bonding. In addition, the results obtained showed that green laser irradiation has positive impact on hydrogen production from water electrolysis compared to the blue laser irradiation.

5. Acknowledgement

The authors like to express their appreciation to the government of Malaysia through research University Grant under Flagship program vote 4F815 for the financial support in this project.

6. References


