OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 11, November 2010, p. 1670 - 1675

Enhancement of Hydrogen by laser focusing during plasma electrolysis of water

M. SHAHID, N. BT BIDIN, A. REHMAN*
Faculty of Science, University technology Malaysia (UTM), Skudai Johor Malaysia

With the increasing energy costs and shortage of oil reserves, production and supply, the need of new energy sources becoming popular in recent days. In concern with global warming and climate change by emission of carbon dioxide with fossil fuel particularly coal has increased the importance of hydrogen. The Production and the enhancement of hydrogen on large scale is a goal towards the revolution of green and cheap energy. Photo catalysis and electrolysis of water are the important methods for production of hydrogen from water. In this paper the role of electrolyte as a photo catalyst was studied during electrolysis of water. The Production and the enhancement of hydrogen from the water have been investigated under the action of diode pumped solid state laser with second harmonic of wavelength 808nm. The efficiency of the hydrogen and oxygen yields was found to be greater than the normal Faradic efficiency. The parametric dependence of the yields as a function of laser beam power, irradiation time is shown. Laser focusing effect and parameters of the electrolysis fundamentals were carefully studied.

(Received September 14, 2010; accepted November 10, 2010)

Keywords: Photo catalysis, Electrolysis of water, Hydrogen, Laser interaction, Oxygen

1. Introduction

We are at the edge of an era of energy crisis. The current energy sources are not able to handle the incoming huge population needs. Hydrogen is used at large scale for production of ammonia, for refining the petroleum and also refining the different metals such as uranium, copper, zinc, tungsten and lead etc. The main source of energy on earth is fossil fuels which cause severe pollutions and cannot last for long time use. Nuclear energy is very expensive and having disposal problems. The other sources such as tidal and wind schemes are not sufficient. The solar, thermal and hydral energy sources are feasible but required a lot of capital. An alternative source is water, which is cheap, clean and everlasting source of global energy. Water contains hydrogen and oxygen. A world-scale hydrogen economy argues that hydrogen can be an environmentally cleaner source of energy to end-users, particularly in transportation applications, without release of pollutants or greenhouse gases at the point of end use. A recent analysis asserted that "most of the hydrogen supply chain pathways would release significantly less carbon dioxide into the atmosphere than would gasoline used in common hybrid electric motors" and that significant reductions in carbon dioxide emissions would be possible if carbon capture or carbon sequestration methods were utilized at the site of energy or hydrogen production. Currently for utilization, hydrogen is produced by different sources such as natural gas, oil, coal and by water. Mainly hydrogen production is 48% from natural gas, 30% from oil, 18% from coal and water electrolysis accounts for only 4%. The Hydrogen production from gas, oil and coal causes serious pollution problems by emitting carbon, lead and other pollutants. The only water is a cheap and clean source of hydrogen Production. The technology is now pointing towards the field of hydrogen by splitting water.

The different methods for production and enhancement of hydrogen from water are used.

Majority of the researchers used plasma electrolysis of water by splitting it into hydrogen and oxygen Fig1.They produced electrolysis of water both light and heavy water [1-11].

Pt-Pd, Pt-Sn, Pt-Ni,pt-W and pt-Ag electrodes are commonly used by the researchers. They used Different electrolytes such as NaCl, NaOH, KOH, K_2CO_3, Na_2CO_3 and H_2SO_4 but the common choice was K_2CO_3, as an electrolyte. Tadahiko Mizuno *et al* [1] reported 80 times greater Hydrogen.

Electrolysis of water reaction is

$$H_2O \rightarrow H_2 + 1/2\, O_2 \tag{1}$$

According to the Faraday's law of electrolysis

$$V = \frac{IRtT}{FPZ} m^3 \tag{2}$$

Where V is the volume of the gas, R is universal gas constant and R=8.314J/mole-K.F is Faraday's constant and F=96485 columb/mol, I is the current in Amperes, T is temperature in K, t is time in seconds, P is pressure in Pascal and Z is number of access electrons.

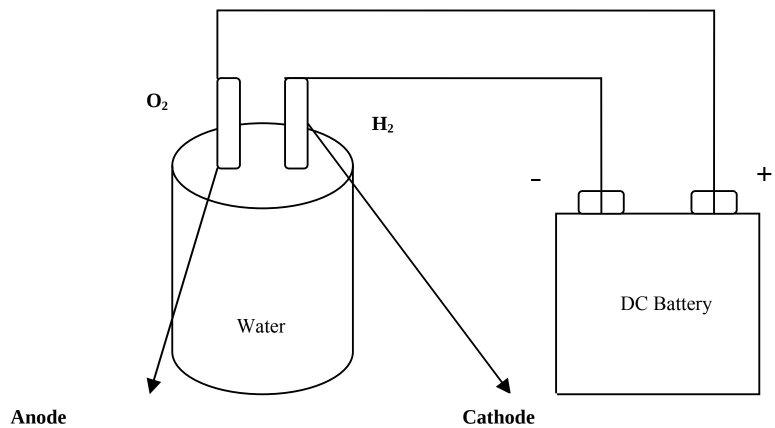

Fig 1. Mechanism of electrolysis.

A lot of research has been done on photo catalytic hydrogen production. The photo catalytic splitting of water using semiconductors has been widely studied [15]. Many scientists produce hydrogen from water by using different photo catalysts in water and reported hydrogen by the interaction of lasers [16-21]. Miyuki Ikeda *et al* [17] used TiO_2 and Gs as a photo catalyst, Byeong Sub kwak *et al* [18] used TiO_2 and Pd, Gondal *et al* [21] used Fe_2O_3 as photo catalyst and produce hydrogen from water. In addition to this photolysis of water has been studied using UV light [22]. Solar energy has been used to obtained Hydrogen from water by photo catalytic process [23, 24].

The most of the scientists demonstrated Hydrogen production from photo ionization of water [12-24]. Giacomo *et al* [12], have investigated hydrogen by irradiating lasers of different energies on water. They dissociate water into hydrogen and Oxygen with the help of radiations IR and UV. Sino *et al* [14], produce Hydrogen by incident gamma rays on water.

Among of many researchers used different product analysis techniques such as SEM (Scanning electron micrograph), EDX (Energy dispersive X-Ray), XRD (X-Ray diffraction), AES (Auger electron Spectroscopy), XPS and TOF-SIMS etc and reported hydrogen in reaction product analysis [22-29]. Hanawa [22] used XPS.Yamada *et al* [23] used EDX and TOFSIMS and analyzed hydrogen in different reactions. Photo catalysis technique is still in the research stage.

Our work on the photo catalysis using lasers has revealed the important parameters which played a vital role in the enhancement of hydrogen from water by laser. Most of the research work basis on photo catalysis has carried out by flash lamps [17-23]. A vary little work is done by lasers [24]. Since laser light has special properties like monochromatic, coherent, intense and polarize, so it was of great interest to use the laser beams as an excitation source in photo catalysis.

The second parameter is related to the nano particles. Semiconducting materials are used as a catalyst [25] in photo catalysis process. We have used electrolyte as a photo catalyst during the plasma electrolysis of water. The third parameter is that the most of the work has done on light water, distilled water and heavy water [1, 33], we have used drinking water for production of hydrogen.

We used different electrolytes as an excitation source. The diode pumped solid state laser having a green light of wave length 808 nm was used as an irradiation source. We investigated the use of electrolyte as a photo catalyst by monitoring the rate of evolved gases i.e. hydrogen and oxygen. We also investigated the dependence of hydrogen and oxygen yields as a laser exposure time, concentration of electrolyte, Faradic efficiency and the effect of laser beam power in the case of plasma electrolysis of drinking water.

2. Experimental setup

A schematic diagram of the hydrogen reactor is shown in Fig. 2. The reactor contained a glass made hydrogen fuel cell having dimension 14 inch X 10 inch. Fuel cell contained a window for irradiation of laser, an inlet for water and electrolyte, two outlets for hydrogen and oxygen gasses, an inlet for temperature probe and a D.C power supply model ED-345B. Two electrodes steel and Aluminum were adjusted in the fuel cell. A CCD camera and a computer triggered with fuel cell for grabbing, a multimeter and gas flow meter are arranged with the fuel cell. The diode pumped solid state laser with second harmonics DPSS LYDPG-1 model DPG-2000 having green light of wavelength 808 nm was placed near the fuel cell for irradiation during electrolysis of water. The drinking water 40 ml mixed with 5 gram electrolyte. In order to start the electrolysis current was applied by D.C source through steal and Aluminium electrodes. The laser beam of wavelength 808 nm from diode pumped laser is incident on water through window of the fuel cell. The hydrogen and oxygen produced was measured by gas flow meter. The laser beam power was measured with the help of a power meter model Nova Z01500. The temperature of the water was measured with the help of Temperature probe i.e. thermocouple thermometer and mercury thermometer. The current was measured with the help of multimeter. The entire experimental run time was 90 minutes. The data was recorded after every minute of the run.

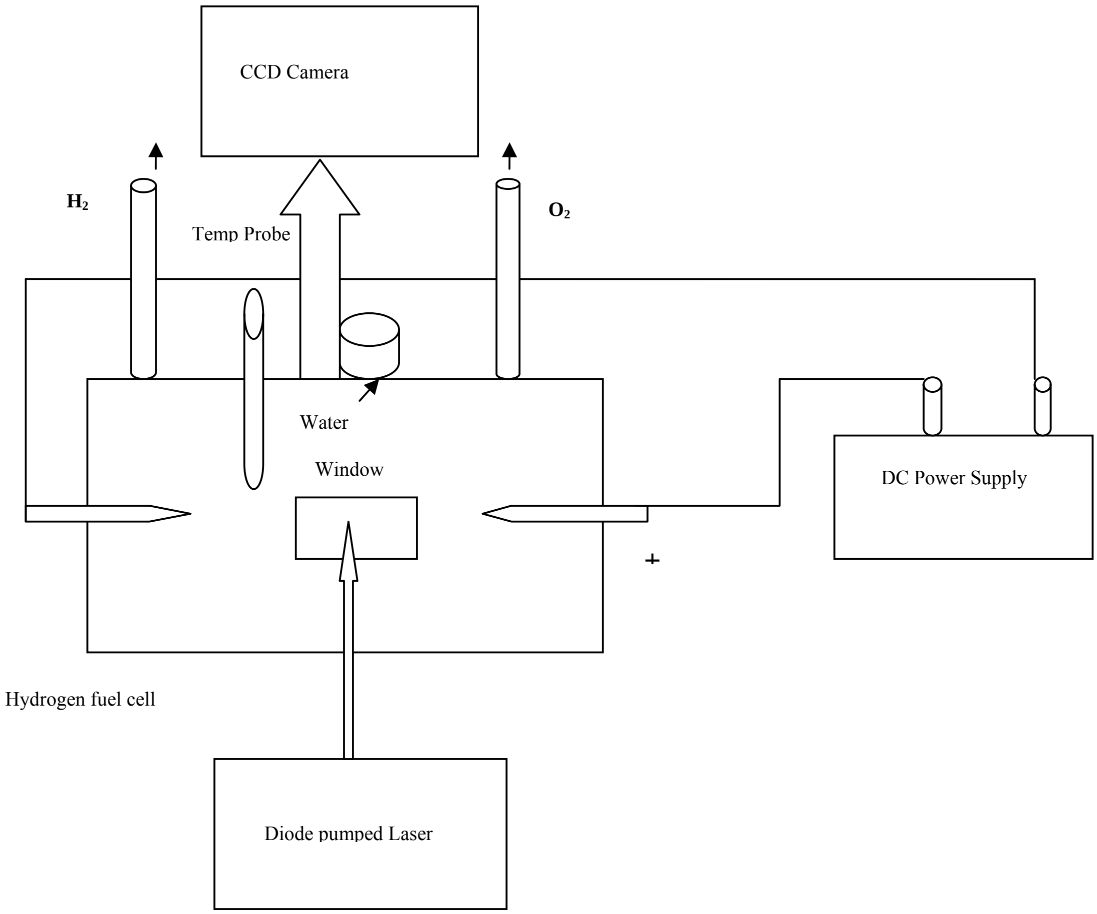

Fig 2. Scheme of hydrogen reactor.

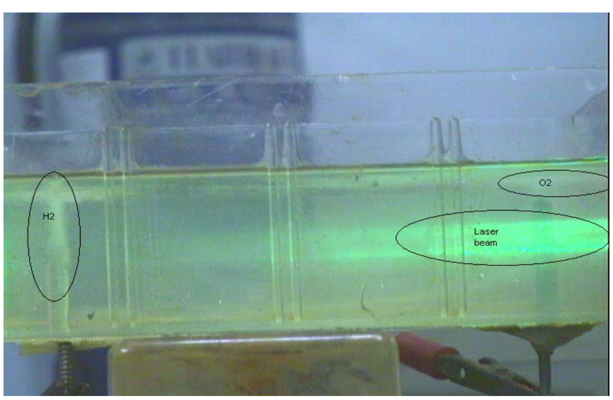

Fig 3. Demonstration of Laser beam interaction, hydrogen and oxygen emission.

Fig. 4. Electrode after corrosion and oxidization.

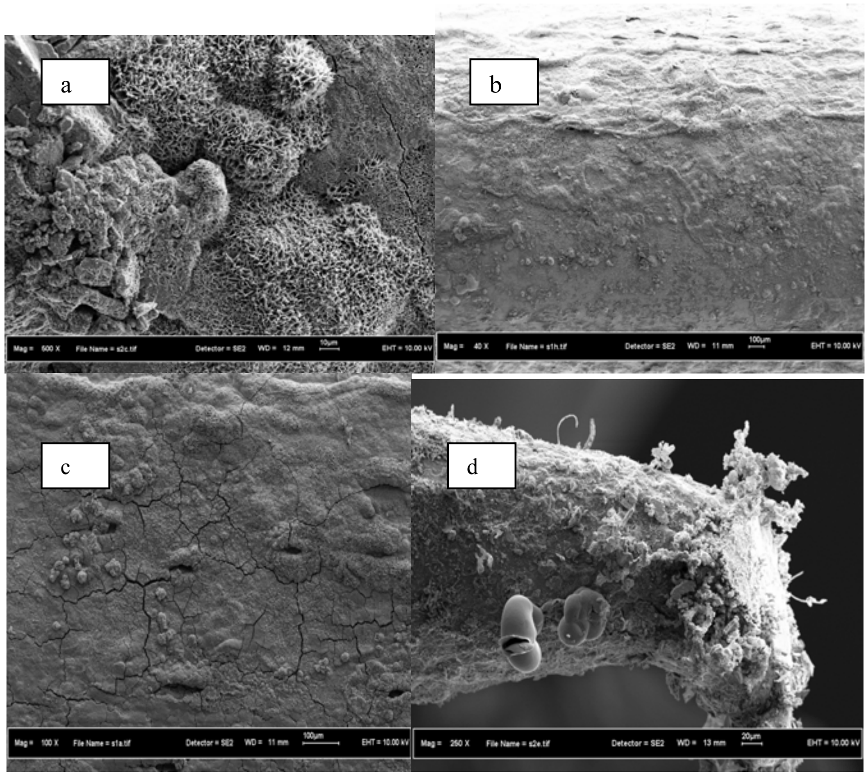

Fig. 5. SEM micrographs of electrodes.

3. Results and discussion

In order to investigate the role of electrolyte as a photo catalyst for water splitting under the influence of laser, various experiments were performed. It has been observed that various important factors affected the yield of hydrogen and oxygen.

(i) Laser exposure time
(ii) Temperature of the water
(iii) Effect of Laser power
(iv) Laser focusing effect
(v) Effect of Temperature on yields
(vi) Selection of electrodes

3.1 Effect of laser exposure time

Fig. 6 represents the relationship between the laser exposure time and the hydrogen and oxygen production rate.

It was observed that the yield of the hydrogen was greater than oxygen. It was because some of the oxygen had used in oxidizing the electrodes and in corrosion process. Fig. 4 and SEM micrographs in Fig. 5 show these oxidizing and corrosion processes upon electrodes.

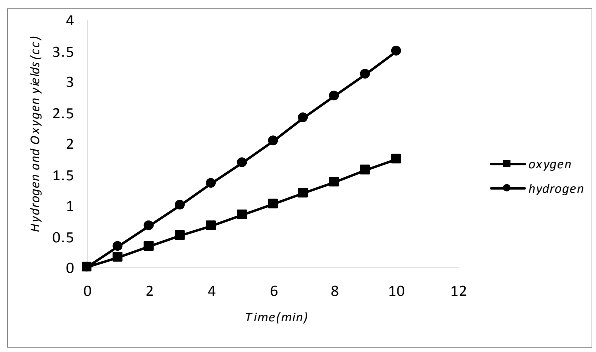

Fig. 6. A graph of laser exposure time versus hydrogen and oxygen yield.

3.2 Effect of temperature

The other important factor which has affected the product yields was the temperature of the water. It has been observed that temperature of the water rose with time.

It was because of Joule heating effect.

$$H = I^2 Rt \text{ (Joules)}$$

Where H is heat dissipation, R is the resistance of water and electrolyte and t is the current rising time. Fig. 7 shows this effect. It has also observed that as long as temperature raised yield of hydrogen and oxygen also increased. It was due to the fact that as temperature of water raised, bonding of the water became week and splitting of water became prominent.

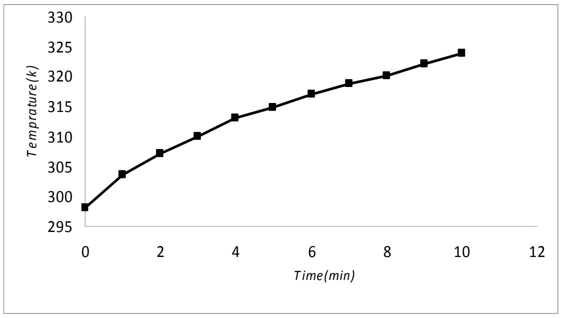

Fig. 7. A graph of laser exposure time versus temperature.

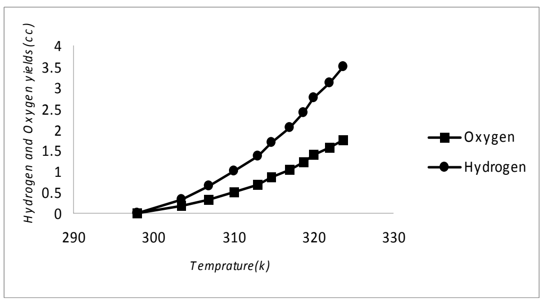

Fig. 8. A graph of temperature versus hydrogen and oxygen yield.

3.3 Effect of laser power

It was also evident from the experimental data that the hydrogen and oxygen productions had effectively depended on laser input power. Fig. 9 represents that the hydrogen and oxygen yields increased linearly with increase in laser power. Where as Fig. 10 represent the effect of laser focusing. It has been observed that the yield of hydrogen changed inversely with distance from the laser focus. The hydrogen production decreased with increase in distance from the laser focus. The emission of hydrogen was found to be higher than the oxygen emission. It was again due to the corrosion and oxidization effects which are seen in Fig. 4 and Fig. 5.

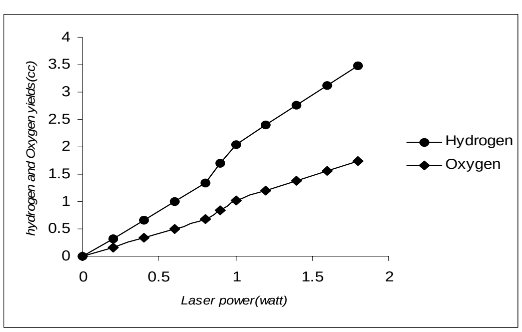

Fig 9. A graph of laser power versus hydrogen and oxygen yields.

3.4 Laser focusing effect

The experimental facts showed that when the hydrogen reactor was near the focus of the laser beam, the yield of hydrogen was found to be large. As long as the distance from the focus was increased the production noticed to be less. Fig. 10 represents this effect. It was due to the fact that when reactor was near the focus the intensity of beam was large, so at that point powers per unit area became large, so yield of hydrogen also became large as in Fig. 9. Similarly when the distance form the focus was increased power per unit area also decreased, so hydrogen yield also became less.

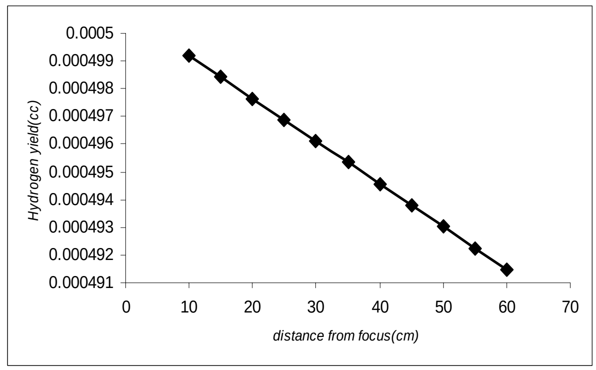

Fig. 10. A comparison between hydrogen yield with and without laser irradiation.

3.5 Selection of electrodes

A lot of electrodes of different material were used during the run. Such as Tungsten, iron, Steel, Aluminum and copper etc. It was observed that most of the electrodes have showed more corrosion and their surfaces were vanished easily during the run of experiment. SEM micro graphs in Fig. 6 shows this corrosion process. The results showed that steel and Aluminum showed less corrosion the other ones. The SEM micrograph B in Fig. 6 was a steel electrode, which showed less corrosion. The steel contains sufficient chromium to form chromium oxide, which prevented it from corrosion both surface as well as block. Similarly the Aluminum is a low density metal which resists the corrosion due to the phenomenon of Passivation. The SEM micrograph C in Fig. 6 was a steel electrode, which showed less corrosion. Where as SEM micrograph A and D in Fig. 6 are copper and tungsten respectively, whish showed more corrosion due to oxidation process.

3.6 Reaction mechanism

The laser beam of energy $h\nu$ was incident on water during electrolysis of water. The excitation of electrolyte then produced the hydrogen and oxygen due to following chemical reaction.

$$h\nu + electrolyte \rightarrow electrolyte^{\bullet} + h\nu^{\bullet} + e$$

$$HO^{\bullet} + HO \rightarrow H_2O_2$$

$$H_2O_2 \rightarrow H_2O \div \frac{1}{2}O_2 \text{ (Anode)}$$

$$e + H^{+} \rightarrow H^{\bullet}$$

$$H^{\bullet} + H^{\bullet} \rightarrow H_2 \quad \text{(Cathode)}$$

$$HO^{\bullet} + H^{\bullet} \rightarrow H_2O$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \text{ (Recombination)}$$

4. Conclusions

The experimental results revealed that electrolyte can be used as a photo catalyst. The diode pumped solid state laser with second harmonics having a green light of wave length 808 nm was highly efficient in photo splitting of water into hydrogen and oxygen during electrolysis of drinking water. The laser focusing effect can enhance the hydrogen during electrolysis of water. The relevant data and results of the experiment exhibited that the production of hydrogen can be increased by using the electrolyte as a photo catalyst during plasma electrolysis of water.

The effect of laser focusing on the geometry and the surface corrosion of electrodes was also an important. This effect is our next future goal.

References

[1] T. Mizuno, T. Ohmori, A. Akimoto "Generation of Heat and Products during Plasma Electrolysis", ICCF-10, (2003).
[2] T. Ohmori, T. Mizuno, Proc. ICCF-7, Vancouver, Canada, 279, (2000).
[3] M. Fujii, S. Mitsushima, N. Kamiya, K. Ota, ICCF9, Beijing, China, May 19-24, (2002).
[4] J. Dufour, J. Foos, J. P. Millot. ICCF-5, Monte-Carlo, Monaco: IMRA Europe, Sophia Antipolis Cedex, France, (1995).
[5] R. Mills, J. He, Z. Chang, H. Zea, K. Akhtar, Y. Lu, C. Jiang, B. Dhandapani, 230th ACS National Meeting, Washington D.C., Aug 28 – Sept 1, (2005).
[6] T. Ohmori, T. Mizuno, ICCF-7, Vancouver, Canada, p.109, April 19-24 (1998a).
[7] T. Mizuno, T. Ohmori, M. Enyo, J. New Energy, **1**(2), 37 (1996).
[8] H. Yamada, S. Narita, Y. Fujii, T. Sato, S. Sasaki, T. Ohmori, ICCF-9, Beijing, China, 123, May 19-24 (2002).
[9] T. Ohmori, H. Yamada, S. Narita, T. Mizuno, Proc. ICCf-9, 284, May 19-24 (2002).
[10] H. Yamada, S. Narita, Y. Fujii, T. Sato, S. Sasaki, T. Ohmori, ICCF-9, Beijing, China, 123, May 19-24 (2002).
[11] Kia Zeng, Dongka Zhang, progress in energy and combustion science, 2009.
[12] A. De Giacomo et al, CNR.IMIP Sec Bari, via Amendola 122/D, 70126 Bari, Italy 2007.
[13] J. Dash, G. Noble, D. Diman, ICCF 4, Lahaina, Maui, (1994).
[14] S. Sino, T. A. Yamamoto, R. Fujimoto, Scripta matter **44**, 1709 (2001).
[15] M. A. Gratzel, Energy resourses through photochemistry and catalysis, New york: Academic press Inc. 1993.
[16] C. S. Cano, MS Thesis, Portland State University, (2002).
[17] C. A. Sacchi, J. Opt. Soc. Amer., B **8**, 337 (1991).
[18] Miyuki Ikeda, catalysis communications 9, 1329 (2008).
[19] Byeong Sub kwak, Bull Korean chem. Soc, **30**(5), (2009).
[20] Daniela Bertuccelli, Héctor F. Ranea-Sandoval, IEEE Journal of Quantum electronics, **37**, (7), July 2001.
[21] C. H. Castano, A. G. Lipson, S. O. Kim, G. H. Miley, Proc. of the ICCF-9, Beijing, China, 24-28, May 19-24 (2002).
[22] R. Simarro, S. Cervera-March, Esplugas S. International journalof hydrogen energy 1985:10:22l INSPEC Compendex.
[23] Specht M. Hydrogen energy press IX. proceeding if the Ninth World Hydrogen energy Conference Paris (France), 527 (1992).
[24] N. Getoff, G. Li, M. Stockenhuber, K. Kotchey, Hydrogen energy progressIX, proceeding if the Ninth World Hydrogen energy Conference Paris (France), 527 (1992).
[25] M. A Gondal Applied catalysis A; genral **286**, 159 (2004).
[26] T. Hanawa, Proc. ICCF-8, Italy, 147, (2000).
[27] H. Yamada, S. Narita, H. Onodera, H. Suzuki, N. Tanaka, T. Nyui, T. Ushirozawa, ICCF 10, (2003).
[28] V. Violante, E. Castagna, C. Sibilia, S. Paoloni, F. Sarto, ICCF 10, (2003).
[29] T. Hanawa, Proc. ICCF-8, Italy, 147, (2000).
[30] X. Z. Li, Y. Deng, Y. J. Yan, H. F. Huang, W. Z. Yu, C. X. Li, J. New Energy, 6, 1, 80 (2001).
[31] G. H. Miley, Proc. ICCF-7, Vancouver, Canada, 241, April 19-24, (1998).
[32] R. Mills, M. Nansteel, P. Ray Plasma Physics, **69**, 131 (2003).
[33] H. Kozima, ICCF-10, (2003).

*Corresponding author: rkamjad@gmail.com