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作品名稱

A Novel Approach of Photogenerated Electron-hole Pairs Transfer in $CuFeO_2$-$Bi_{20}TiO_{32}$ Photocatalytic Water Splitting Combined with a PEM Fuel Cells

得獎獎項

化學科大會獎二等獎

莫斯科正選代表: 2010年莫斯科國際科學博覽會

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關鍵詞：Photocatalyst、Water-splitting、Fuel Cell

作者自傳

我叫羅紹儒，目前就讀麗山高中高二數理資優班。

上了高中之後，對於許許多多不同領域的學習都有極大的興趣，不論是在語文方面參加的文藝營、英語研習等等的活動，或者是科學方面的中央研究院物理培訓計畫、高中物理辯論賽獲得金牌的榮耀等等都是高中生涯中的點點滴滴。然而過程當中，難免花費了許多的時間在這些活動上，進而疏忽了學業。

起初的我，不以為然。然而科教館給予我的這個接觸科學實驗的機會再加上在中研院長期的學習，卻改變了我這樣的態度。實驗、思考、創意固然重要，然而這些重要的因素卻都是建立在對於紮實的學問上。沒有了紮實的學問，設計的實驗時常會漏洞百出或者時常出錯，便不能夠有效的完全一套完整的實驗！

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摘要

氣候暖化是一個地球目前正面臨的一大議題，造成地球暖化的主要原因是長期大量使用的化石性燃料所產生的二氧化碳等溫室氣體因此尋找一個替代性的能源是一個當今十分重要的問題。本研究將可見光光觸媒 $Bi_{20}TiO_{32}$、$CuFeO_2$ 粉體及鐵絲網懸浮於內照式光觸媒觸媒反應器內，當受激發之光觸媒粉體與鐵絲網發生碰撞，則可使光生電子-電洞經金屬-半導體異相介面傳遞至另一光觸媒之活性位置，藉此有效地分離光生電子-電洞而提高光觸媒水分解之產氫速率。本研究發現，利用此一光生電子-電洞傳遞途徑，在 293 K 下 $CuFeO_2$ 之光觸媒活性可達 8.38 mL H_2/min · g。然而，本研究中光觸媒水分解之產氫速率在沒有氣體壓縮器的協助下，未能有效地驅動質子交換膜燃料電池。本研究亦探討質子交換膜燃料電池之最佳化條件，發現在 333 K 下，以 100 mL/min 純氫作為進料，可使質子交換膜燃料電池在 0.6 V 之操作電壓下，輸出 0.78 W 之電能。在未來，將本研究發展之光觸媒反應系統與質子交換膜燃料電池結合成光電能轉換系統，則可能夠在日常生活中有效地被運用。

Abstract

A novel approach of photogenerated electron-hole pairs transfer in the photocatalytic reaction for water splitting were proposed in this work. The photocatalyst powders, a mixture of $CuFeO_2$ and $Bi_{20}TiO_{32}$, and an iron net were suspended in an inner-irradiation photocatalytic reactor which contains 10 vol% methanol solution in order to create an approach of excitons transfer in the metal-semiconductor heterojunctions when the photoexcited $CuFeO_2$ and $Bi_{20}TiO_{32}$ powders, individually, collide with the surface of an iron net. The photocatalytic activity of $CuFeO_2$ is 8.41 mL H_2/min·g at 293 K in the present work. However, the evolution rate of hydrogen product in this system is insufficient to drive a proton exchange membrane fuel cell (PEMFC), unless a gas compressor is being developed. In addition, an investigation on the operating conditions of a PEMFC indicates that under the operating condition of pure hydrogen flow of 100 mL/min in feed rate at 333 K, the obtained maximum power density is 0.78 W at 0.6 V. In the future, a composite system of the developed photoelectrochemical device in this work and a PEMFC is promising to be further scaled up for a practical application in daily life.

Motivation

After hearing a splendid speech by Prof. Steven Chu, a noble prize winner, at the Academy Presidents' Forum, I have learned about the importance of finding a clean energy in replacement of fossil fuel. There are several types of energy that are mentioned by him in his speech, but he emphasized that biomass energy, solar energy and fuel cells are important future prospects.

Therefore, I did lots of research on biomass, solar energy and fuel cells, while encountering the book "Fuel Cell Handbook", I found out that the hydrogen that are needed for a Proton Exchange Membrane Fuel Cell (PEMFC), are mostly provided through hydrogen tanks. Having the knowledge of this fact, I started thinking if there was a way to replace hydrogen tanks by something that has the ability to provide hydrogen without causing damage to the environment. More and more research was done, and I've discovered that photo-catalyst has the ability to produce hydrogen by just splitting water!

Thus, I came up with the idea of transporting the hydrogen produced by photo-catalyst directly towards a PEMFC, hoping that with both solar energy and fuel cell being extremely clean energy, this project will develop an even more eco-friendly cell

Objective

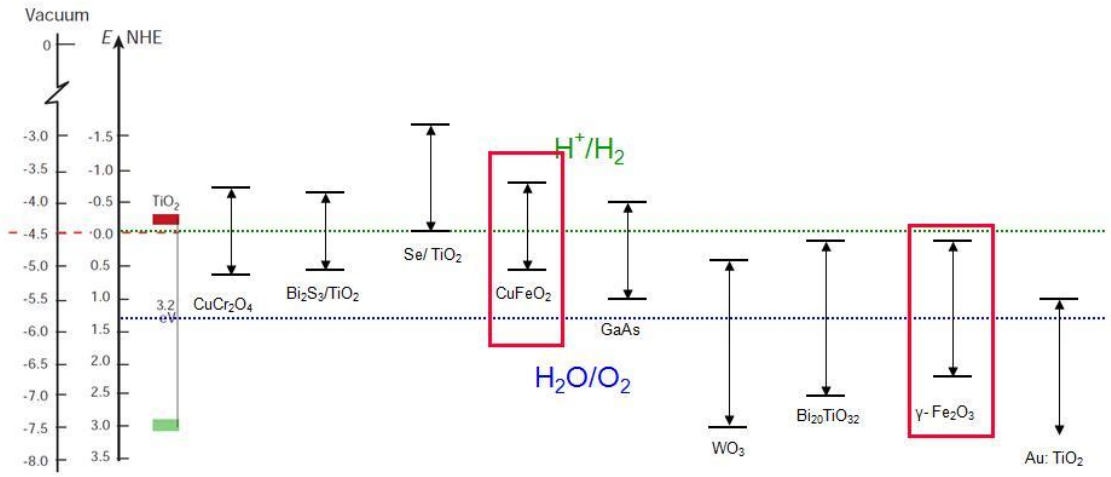
This project is objected to develop a novel composite system of solar cell and fuel cell. The solar cell used in this project is known as a Photoelectrochemical (PEC) Device, and as for fuel cell, this project will be using a Proton Exchange Membrane Fuel Cell.

1. Enhancement on the evolution of hydrogen
2. Effects of hydrogen's flow rate on PEMFC
3. Construction of a fuel cell system using hydrogen produced from photocatalyst as fuel
4. Construction of a novel water-splitting photocatalyst system, and investigation on its' purity and evolution of hydrogen
5. Discussions on discharge curve of the novel fuel cell system

Introduction

A. Photocatalyst

I. Band Gap Evaluation



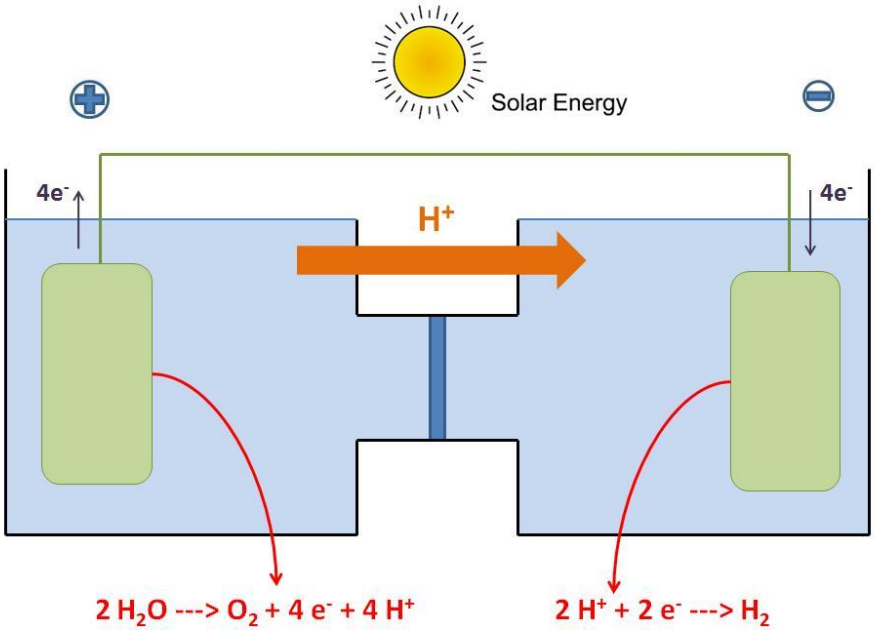
Photocatalyst	$CuCr_2O_4$	Bi_2S_3/TiO_2	Se/ TiO_2	$CuFeO_2$	GaAs	WO_3	$Bi_{20}TiO_{32}$	Fe_2O_3	Au: TiO_2
Conduction band	-0.74eV		-1.65eV	-0.82eV	-0.4eV	0.5eV	0.22eV	0.69eV	1eV
Valence band	0.61eV		0.3eV	0.52eV	1.0eV	3.1eV	2.60eV	3.14eV	3.14eV
Band gap	1.35eV	1.28eV	1.95eV	1.34eV	1.4eV	2.6eV	2.38eV	2.45eV	2.14eV

These are some photocatalyst that we found through research by search engines for international articles. The band gap value is crucial for being a photocatalyst, since when the band gap value is too small, the wavelength of ligh absorption would be too low (explained in the section III of introduction: Effect of Band Gap Value on Absorption Wavelength).

Furthermore, the conduction band and valence band of the photocatalyst is as important. When the valence band of the catalyst lies above the eV value of 1.32 eV (v. NHE), oxygen will be produced; while, when the conduction band of the catalyst lies above 0 eV (v.NHE), hydrogen will be produced.

Therefore, we researched for photocatalysts that crosses the band values for producing either hydrogen or oxygen, in order to find solution for producing high purity of hydrogen and oxygen for our fuel cell.

II. Photoelectrochemical Water Splitting



(Schematic Diagram of Photoelectrochemical Device)

This is a photoelectrochemical (PEC) device, which the oxygen and hydrogen are being produced separately.

The anode side releases electrons, which turns water into oxygen and hydrogen ion; while the cathode side oxidizes the hydrogen ion, turning it into hydrogen.

Between the two chambers, there will be a membrane to separate the liquid inside the device, but having the ability to let hydrogen ions to pass through. For instance, Nafion® proton exchange membrane is a type of membrane that only allow hydrogen to pass through, but not water.

III. Effect of Band Gap Value on Absorption Wavelength

$$E = h\nu$$

$$\nu = \frac{c}{\lambda}$$

$$E = \frac{hc}{\lambda}$$

$$c = 2.99792458 \times 10^{17}\, nm/s$$

$$h = 4.13566733 \times 10^{-15}\, eV \cdot s$$

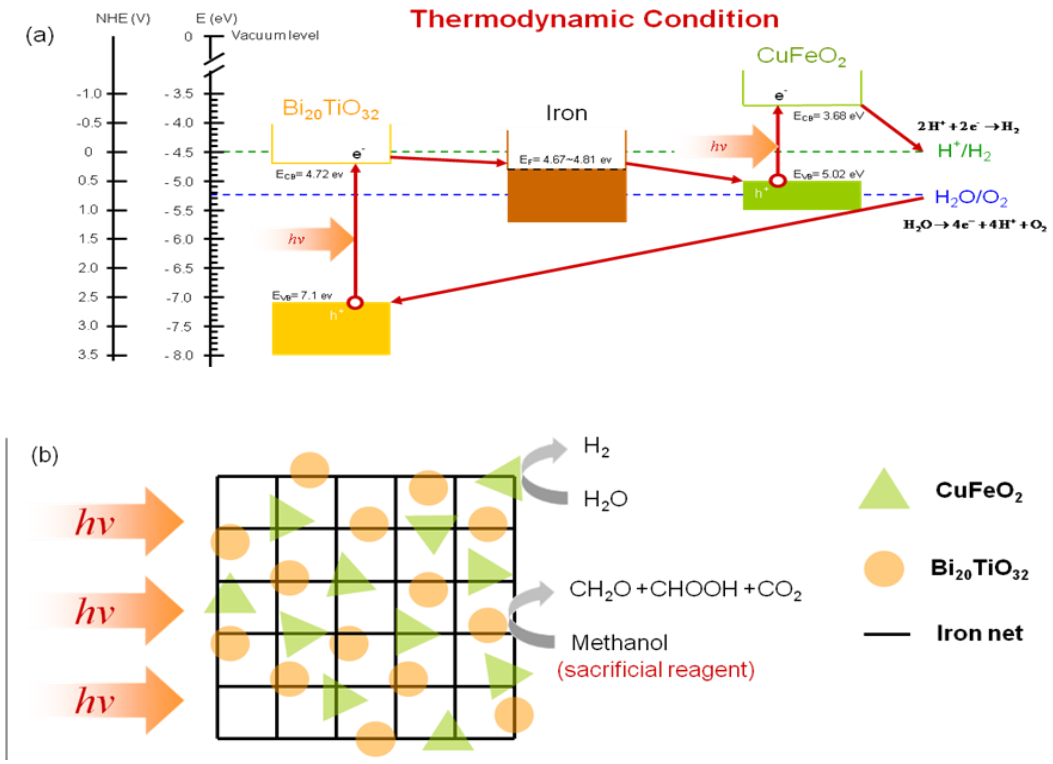
$$E = \frac{\left(2.99792458 \times 10^{17}\, nm/s\right) \times \left(4.13566733 \times 10^{-15}\, eV \cdot s\right)}{\lambda}$$

$$E = \frac{12.39 \times 10^{2}\, eV \cdot nm}{\lambda} = \frac{1239 eV \cdot nm}{\lambda}$$

According to the Planck's Law and some further calculation, we can find that the absorption wavelength of the photocatalyst can be done by determining its' band gap value.

From the calculation, in order to absorb a visible-light wavelength, the band gap value of the photocatalyst has to be below 3.09 eV and above 1.23 eV.

IV. Approach of Photogenerated Electron-hole Pairs Transfer



Through iron net, photogenerated electron hole pairs can be separated efficiently, therefore, it will increase the photoactivity of the catalysts.

Materials

Chemicals:

Product	Molecular Formula	Molar Weight	Brand	Purity
Iron(III) nitrate nonahydrate	$Fe(NO_3)_3$	403.99	ACROS	
Copper(II) nitrate trihydrate	$Cu(NO_3)_2$	241.60	ACROS	
Bismuth(III) nitrate pentahydrate	$Bi(NO_3)_3$	485.07	ACROS	
Tantalum(V) chloride	$TaCl_5$	358.21	ACROS	
Sodium Hydroxide	NaOH			
Iron(II) chloride tetrahydrate	$FeCl_2 \cdot 4H_2O$	198.81	ACROS	
Citric Acid	$C_6H_8O_7$	192.13	ACROS	
Nitric Acid				
Ammunia	NH_4OH		ACROS	30wt%
Hydrogen Peroxide	H_2O_2			
EDTA				
Glucose				
Acrylamide Monomers				
Propylene Oxide	CH_3CHCH_2O	58.08	ACROS	
Ethanol				
Methanol				
Acetone				
Glass cleaning			Merck	
Nafion 212			DuPont	
Nafion 117 Solution			DuPont	97~100%
Chromium(III) Oxide	Cr_2O_3		ACROS	
Copper Oxide	Cu_2O		ACROS	
Iron Oxide	Fe_2O_3		ACROS	
α-Bismuth (III) Oxide	α-Bi_2O_3		Alfa Aesar	

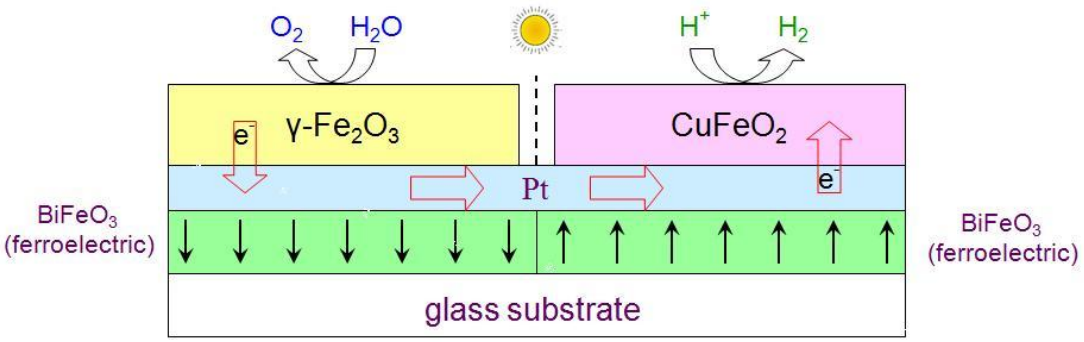
Equipments:

Product	Brand	Amount
Furnace	Barnstead Thermolyne 48000	1
Cubicle Furnace	Lindberg	1
Magnetic Stirrer/ Hot Plate	Corning	1
Mechanical Stirrer	NS	1
Weighting Balance	Precisa 40SM-200A	1
3D Mixer	WAB Turbula System Schatz	1
UV-Visible Light Spectrum	JASGO V-560	1
Thermometer	NS	1
Pipette	Eppendorf	1
pH-meter	Mettler Toledo	1
Oven	Deng Yng DOS45	1
XRD (X-Ray Diffusion)	Rigaku Dmax-B	1
SEM (Scanning electron microscope)	JEOL JSM- 6500F	1
ICP (Inductively coupled plasma atomic emission spectroscopy)		1
Hot Presser	Hephas Energy	1

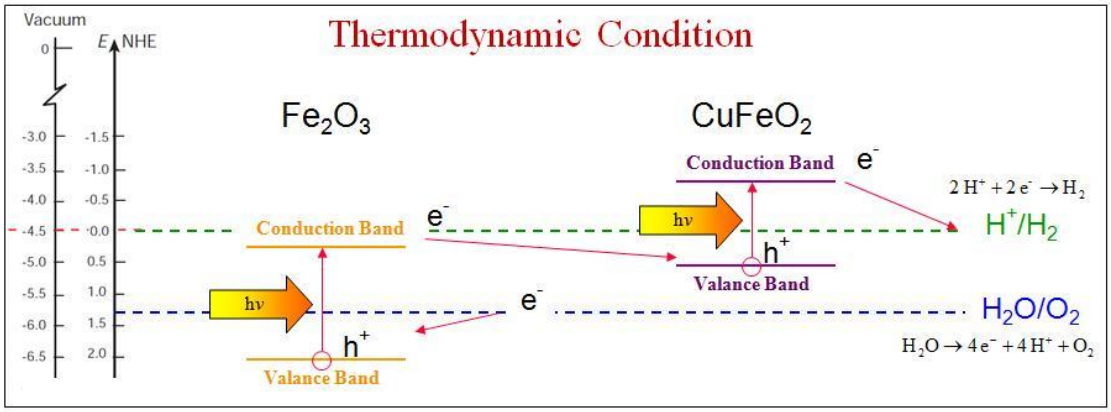
*NS = Not Stated

Experimental

A. Design of Photoelectrochemical (PEC) Device



A schematic diagram of the design of Photoelectrochemical Device, showing the way hydrogen is going to be produced. The selection of photocatalyst is due to their band gap and the positions of their conduction band and valance band.

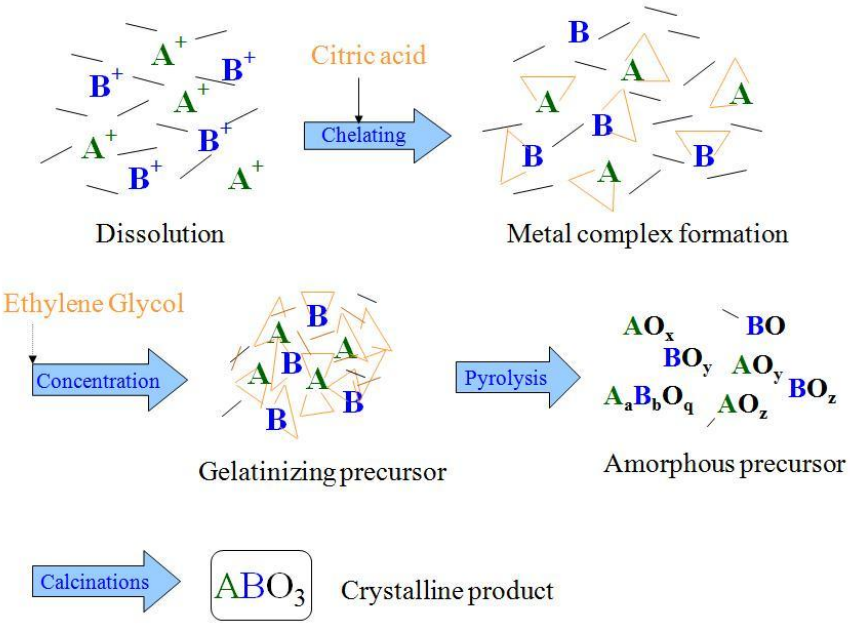


The conduction band of Fe_2O_3 is lower than the conditions that produces H^+, meaning that Fe_2O_3 only produces oxygen under light; while, the conduction band of $CuFeO_2$ crosses the conditions that produces H^+, but not producing oxygen. Therefore, from this design, the production of hydrogen and oxygen will be produced separately when encountering light.

Photocatalyst

I. $CuFeO_2$

1. Sol-Gel Method



Sol-Gel Method, also known as Pechini method, is a cheap and low-temperature technique that allows fine control of the product's chemical compositions. Starting with the dissolution of the selected metal salts, then citric acid will be added, chelating the two metal salts into metal complex formations. After adding ethylene glycol, or drying process, the metal complex formation will be concentrated into gelatinizing precursor. While after pyrolysis, forming an amorphous precursor, calcinations will be done to provide the crystalline product for further examination and usage.

2. Conditions

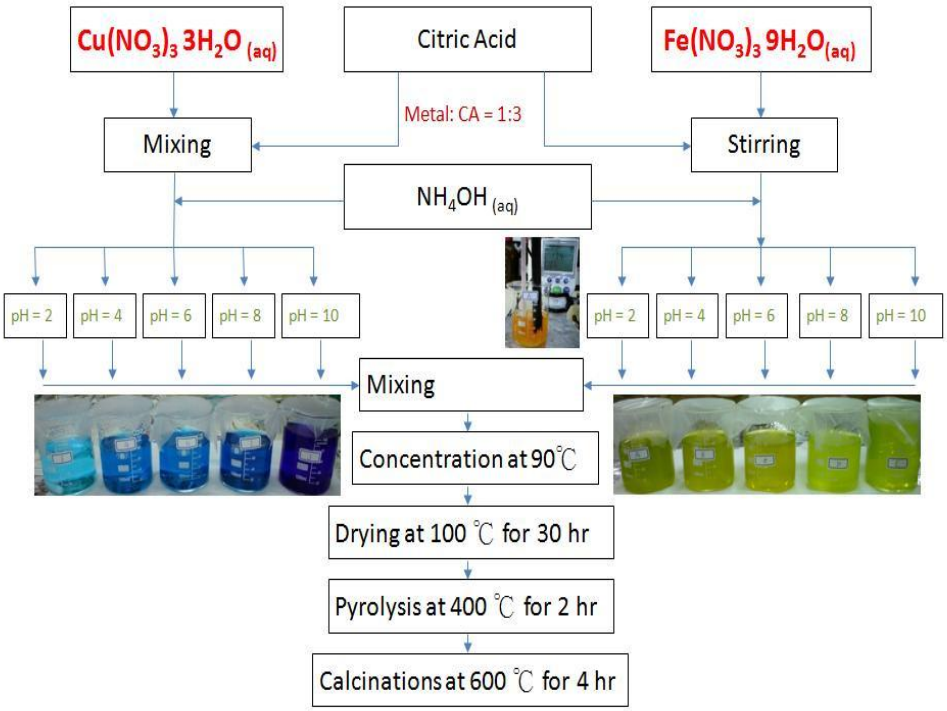
(1) Experimental Setup 1

(a) Purpose: Investigation on different pH values of Fe-citrate and Cu-citrate on the crystalline formation of $CuFeO_2$

(b) Chemicals:

Chemical	Formula	Molecular Weight
Copper(II) nitrate trihydrate	$Cu(NO_3)_2 \cdot 3H_2O$	241.6g/mol
Iron(III) nitrate nonahydrate	$Fe(NO_3)_3 \cdot 3H_2O$	404g/mol
Citric acid	$C_6H_8O_7$	255g/mol

(c) Procedures:



a. Weigh out 16.4999g of $Fe(NO_3)_3$ from glove box and dissolve in DI water
b. Weigh out 19.1319g of $Cu(NO_3)_2$ from glove box and dissolve in DI water
c. Adjustment of pH value by ammunia of both Fe-nitrate solution and Cu-nitrate solution to pH values 2, 4, 6, 8, 10
d. A mixture of molar ratio Cu : Fe = 1 : 1 is mixed thoroughly with assistance of magnetic stirrer
e. Concentration was done at 90℃ under stirring and control of temperature by hot plate
f. Drying at 100℃ for 30 hr

g. Pyrolysis at 400℃ for 2 hr

h. Calcinations at 600℃ for 4 hr

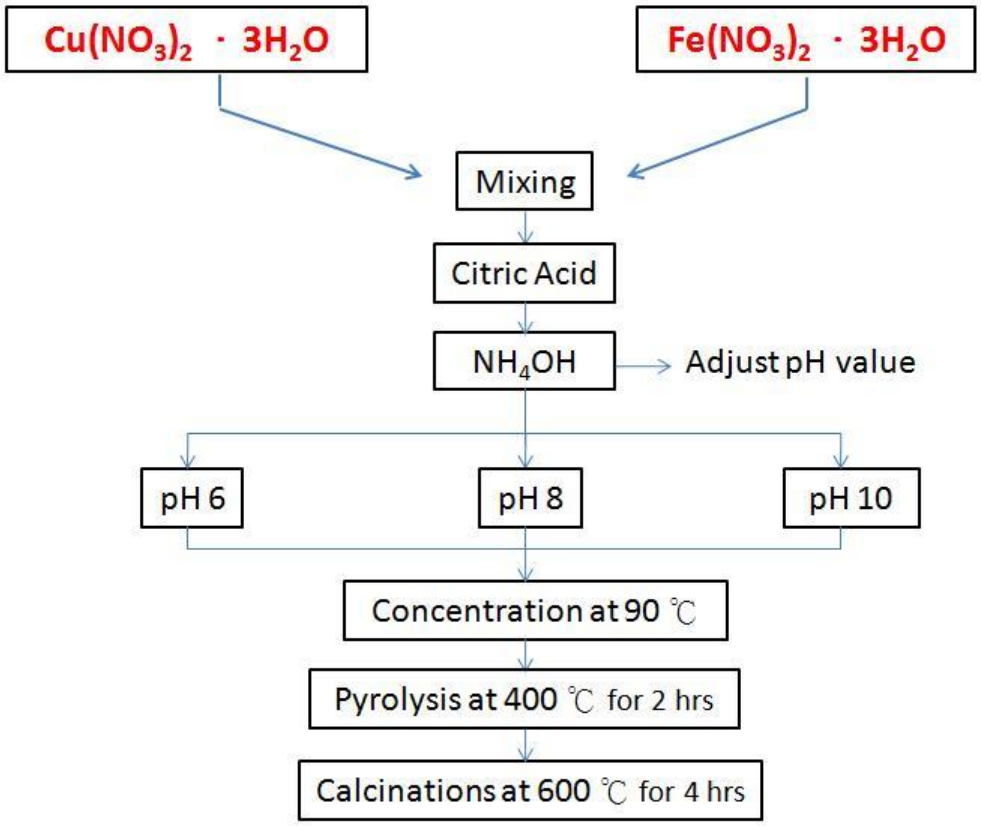
(2) Experimental Setup 2

(a) Purpose: Investigation on improvement to crystalline formation of $CuFeO_2$ when metal salt are added beforehand

(b) Chemicals:

Chemical	Formula	Molecular Weight
Copper(II) nitrate trihydrate	$Cu(NO_3)_2 \cdot 3H_2O$	241.6g/mol
Iron(III) nitrate nonahydrate	$Fe(NO_3)_3 \cdot 3H_2O$	404g/mol
Citric acid	$C_6H_8O_7$	255g/mol

(c) Procedures:



a. measure out 5mL of 0.7381M Fe(NO3)3 and 5.149ml of 0.7168M Cu(NO3)2, and mix for 30 min

b. ICP is done to determine the concentration of the Fe and Cu in each solution

c. measure out 14.1811 g of citric acid and dissolve it with 100ml DI water to form a 0.7381M citric acid

d. add 30ml of citric acid into the mixture of Fe and Cu, and stir for 5 min

e. NH4OH is used to adjust the pH from 0.71 to 10.01 at 36.1

f. Pyrolysis at 90 ℃ until it reaches a gluey status

g. Calcinations at 400 ℃ for 4 hr

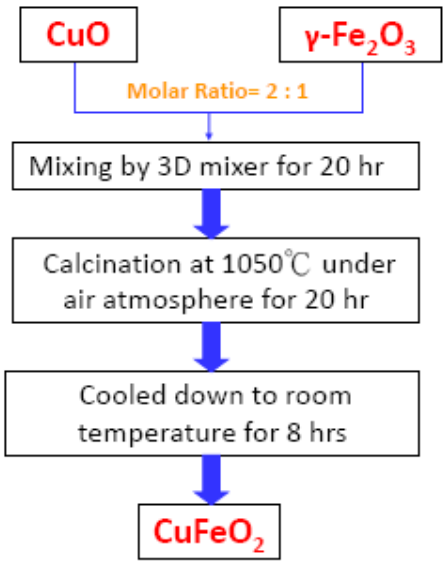
(3) Experimental Setup 3

(a) Purpose: Investigation on using solid state method of preparing $CuFeO_2$

(b) Chemicals:

Chemical	Formula	Molecular Weight
Copper Oxide	CuO	79.55g/mol
Iron Oxide	γ -Fe_2O_3	159.7g/mol

(c) Procedures:



a. measure out 1.0003 g of CuO and 1.0004 g of gamma-Fe_2O_3 with a molar ratio of 2:1

b. Have the mixture added with Zirconium Oxide balls, to mix them more throughly on the 3D mixer

c. The mixture is heated at 1050℃ for 20 hours under air flow

d. The product will be cooled down to room temperature

II. Preparation of $Bi_{20}TiO_{32}$

1. Solid-State Method

2. Conditions:

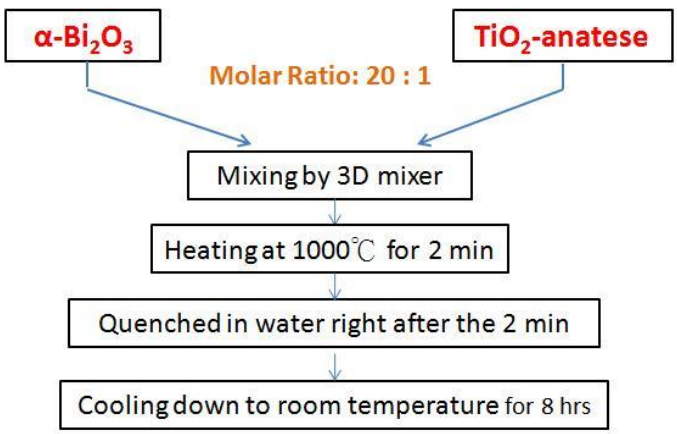
(1) Experimental Setup

(a) Purpose: To prepare a substitute for catalyst γ-Fe_2O_3 , and test for it's hydrogen productivity in our reactor

(b) Chemicals:

Chemicals	Formula	Molecular Weight
α-Bismuth Oxide	α-Bi_2O_3	465.96g/mol
Titanium Oxide Anatase	TiO_2	79.90g/mol

(c) Procedures:



a. 0.1001 g of TiO2 and 11.6665g of α-Bi_2O_3 are mixed thoroughly through a 3D mixer and Zirconium Oxide ball

b. The mixture is being heated to 1000 for 2 min

c. Immediately quench the mixture into water after being heated to 1000 for 2 min

d. Cooled down to room temperature for 8 hrs

III. Preparation of $CuCrO_2$

1. Solid-State Method

2. Conditions:

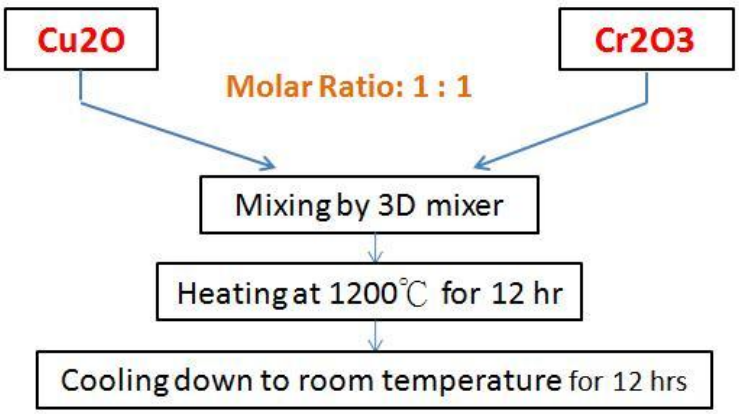
(1) Experimental Setup

(a) Purpose: To prepare a substitute for catalyst $CuFe0_2$, and test for it's hydrogen productivity in our reactor

(b) Chemicals:

Chemicals	Formula	Molecular Weight
Copper Oxide	Cu_2O	143.1g/mol
Chromium(III) Oxide	Cr_2O_3	152g/mol

(c) Procedures:

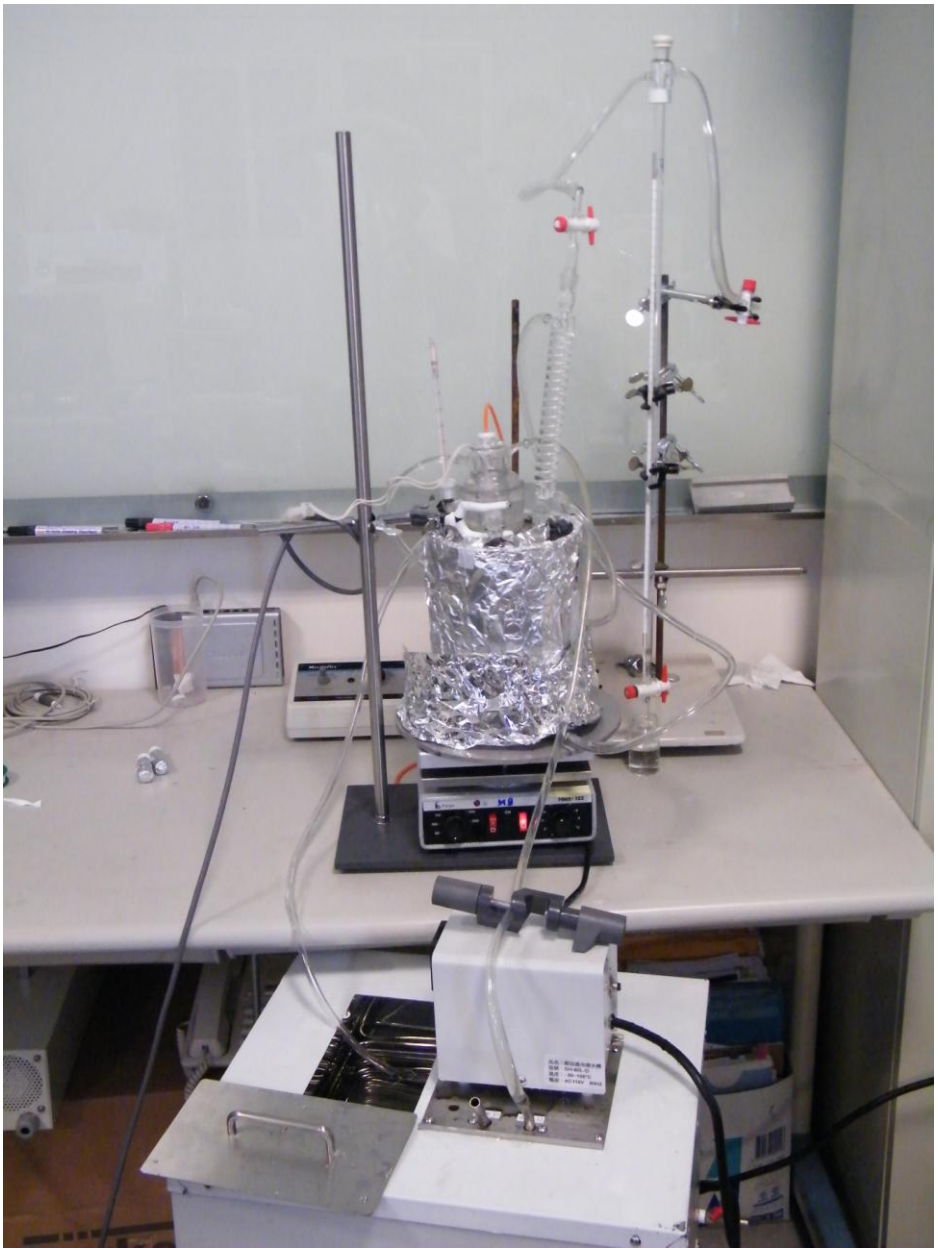


a. 2 g of Cu_2O and 2.1244g of Cr_2O_3 are mixed thoroughly through a 3D mixer and Zirconium Oxide ball

b. The mixture is being heated to 1200 for 12 hrs

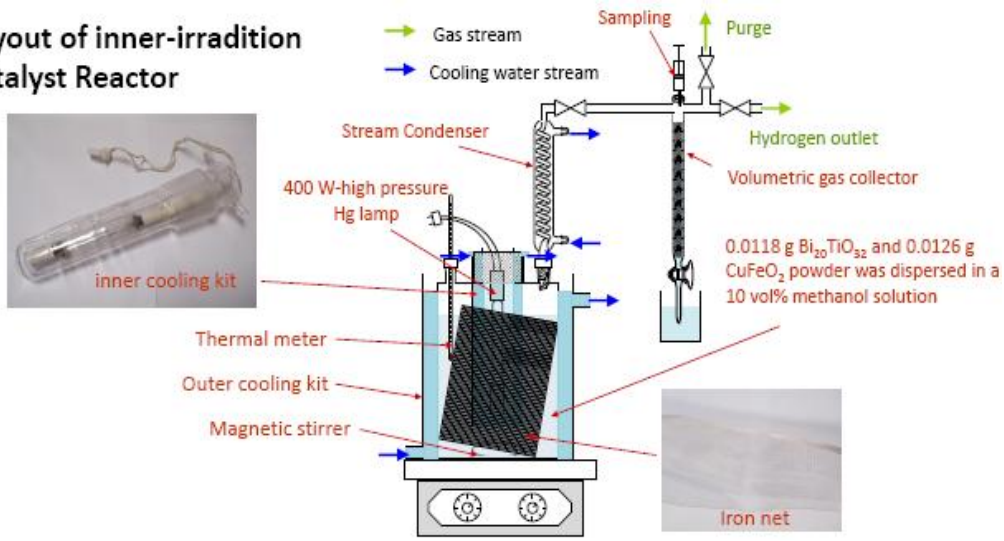
c. Cooled down to room temperature for 12 hrs

IV. Reactor



(Picture of the reactor)

Fig. 7. Layout of inner-irradition Photocaltalyst Reactor



The reactor is designed for suspended photocatalysts. The light source in the middle is a 400W high-pressure mercury lamp, while the amount of hydrogen evolved is determined through the numeric change on the scale of gas collector. The cooling kit is made of quartz for better light transmittance. Pure water and methanol is added as reactant solutions for water splitting, and a magnetic stirrer is used to cause turbulence to the reactant solution.

B. Fuel Cell

I. Preparation of the MEA

1. Purpose: to combine the membrane with GDL to form a workable MEA for testing

2. Conditions:

(1) Experimental setup

(a) Conditions:

a. temperature set at 140 ℃

b. pre-pressure set at 20 kg/cm^2 for 180 seconds

c. mid-pressure set at 50 kg/cm^2 for 90 seconds

d. final-pressure set at 100 kg/cm^2 for 90 seconds

(b) Chemicals:

Chemical	Formula	Product
Nafion® 117 solution		
Nafion® 212 membrane		
Carbon Cloth with Pt catalyst, wet proofed		LT140-EWSI

(c) Procedures:

a. Nafion® 117 solution and Nafion ® 212 were produced by DuPont® to serve as the raw materials needed for the Membrane Electrode Assembly(MEA), while the carbon cloth with Pt catalyst ($0.5mg/cm^2$), wet proofed, was produced by E-Tek® .

b. Prepare the Nafion® 212 into a piece of 4 cm x 4 cm size, while the carbon cloth prepared into two pieces with size 3 cm x 3 cm.

c. Place the first piece of carbon cloth on the graphite loader, then place the Nafion® 212 membrane on top of the carbon cloth.

d. Adjust the Nafion membrane to the center of the carbon cloth. Then place the second carbon cloth onto the Nafion membrane, make sure that the carbon cloth overlaps each other.

e. Place the above combined product onto the hot presser.

f. Set the conditions of the hot presser as mentioned above

g. After hot-pressing, carefully remove the graphite loader from the hot presser, until the temperature is cooled to room temperature

h. Remove the MEA from the graphite loader and place it into a clean plastic container, before further use

II. Assembling the Proton Exchange Membrane Fuel Cell

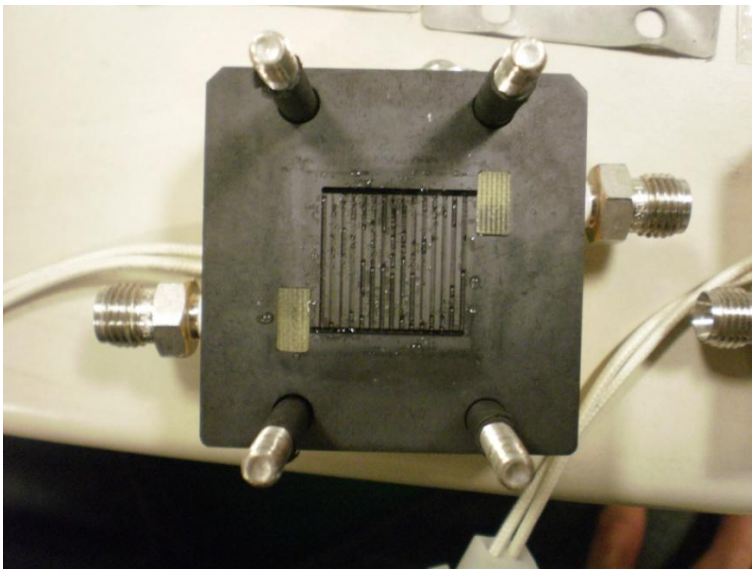
1. Purpose: to combine a complete functional fuel cell for further testing

2. Conditions:

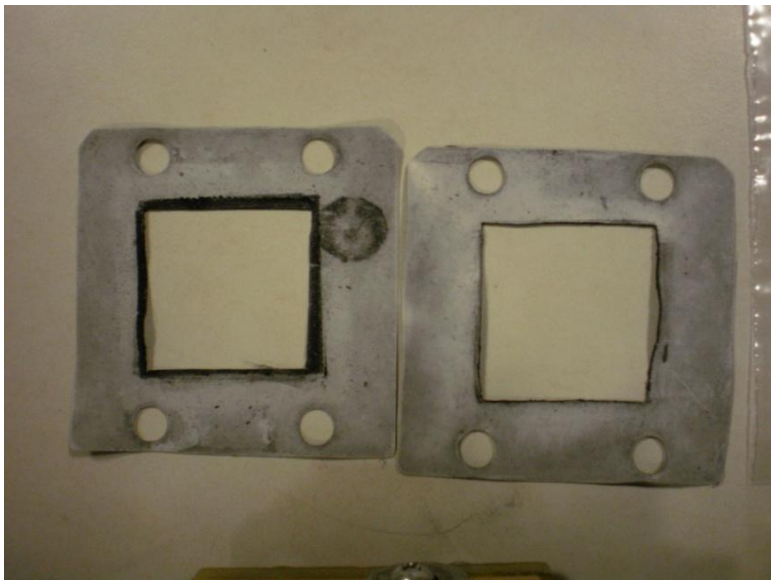
(1) Experimental setup

(a) Procedures:

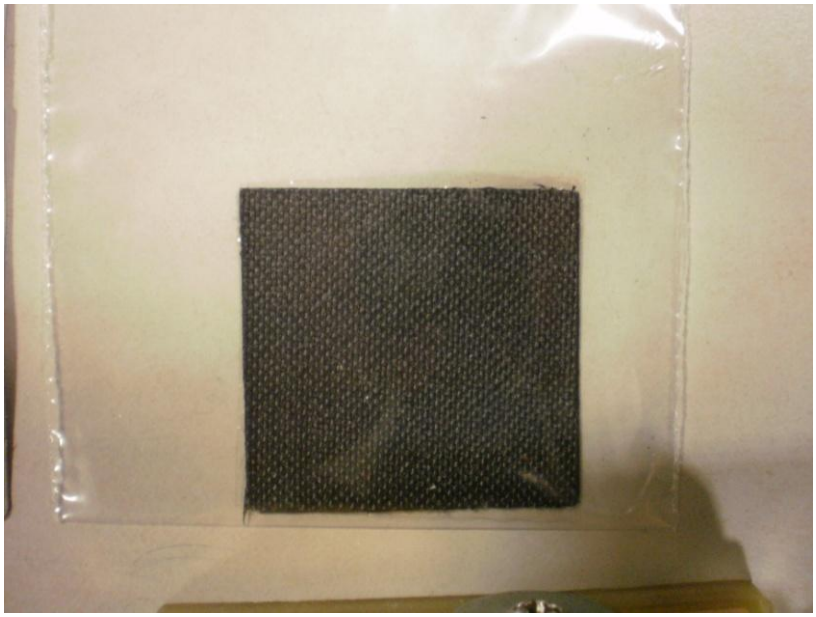
a. Ethanol is used to clean up the graphite block



b. Teflon gasket is placed onto the graphite block



c. Place the prepared MEA onto the teflon gasket



d. Place the other piece of gasket onto the MEA

e. Have the entire fuel cell locked up, the pressure for the screw's lock on the fuel cell up is around 40 kgf · cm

f. Connect the anode and cathode to the fuel cell, waiting to be tested.

III. Testing of PEMFC

1. Purpose: parameters are set to evaluate the lowest amount of hydrogen needed for the fuel cell to work properly.

2. Conditions:

(1) Experimental Setup:

(a) Conditions:

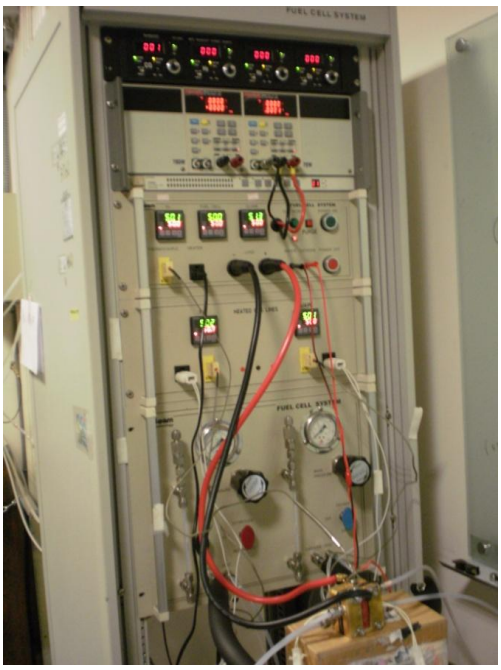
Conditions	Values
Temperature	30℃, 40℃, 50℃, 60℃, 70℃, 80℃
Ratio of Nitrogen added to Hydrogen	5%, 10%, 20%, 30%,
Amount of Hydrogen	10, 25, 50, 100, 200 (ml/min)

(b) Chemicals:

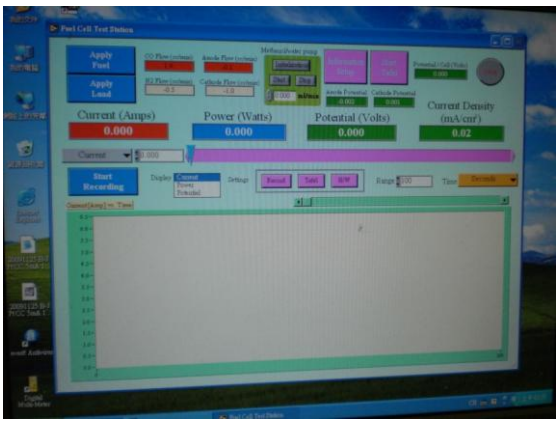
Products	Formula
Hydrogen	H_2
Oxygen	O_2
Nitrogen	N_2

(c) Procedures:

a. Temperature is being adjusted on the fuel cell system



b. The ratio of nitrogen and amount of hydrogen is being controlled by the fuel cell testing system called “Beam”, developed by Beam company



C. Combination

I. Discussions on discharge curve

1. Purpose: to observe whether the combination of the novel PEC device and the PEMFC has a functional output of current.

2. Conditions:

(1) Experimental Setup:

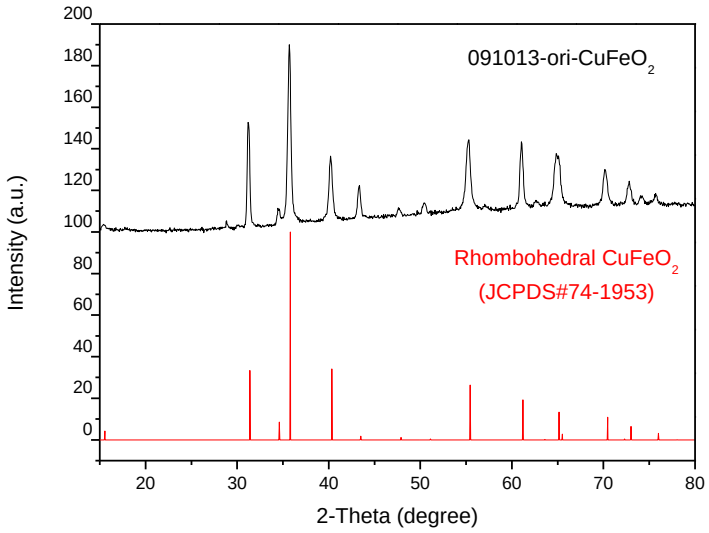
(a) The discharge curvce will be captured and graphed using the same program used for testing PEMFC, the program “Beam”

Results and Discussion

A. Photocatalyst

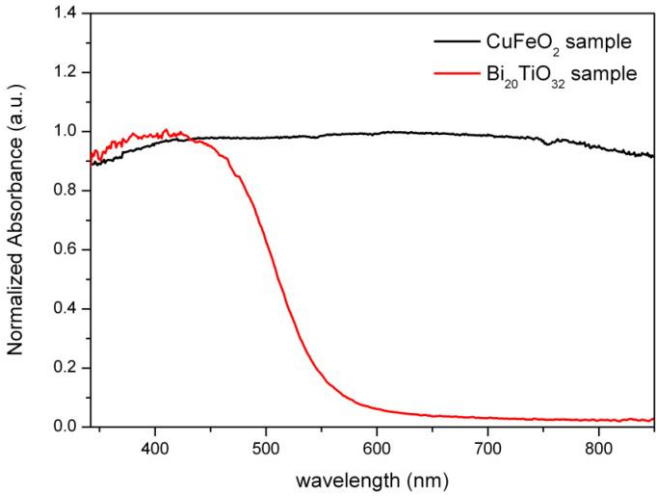
I. $CuFeO_2$

1. XRD Analysis



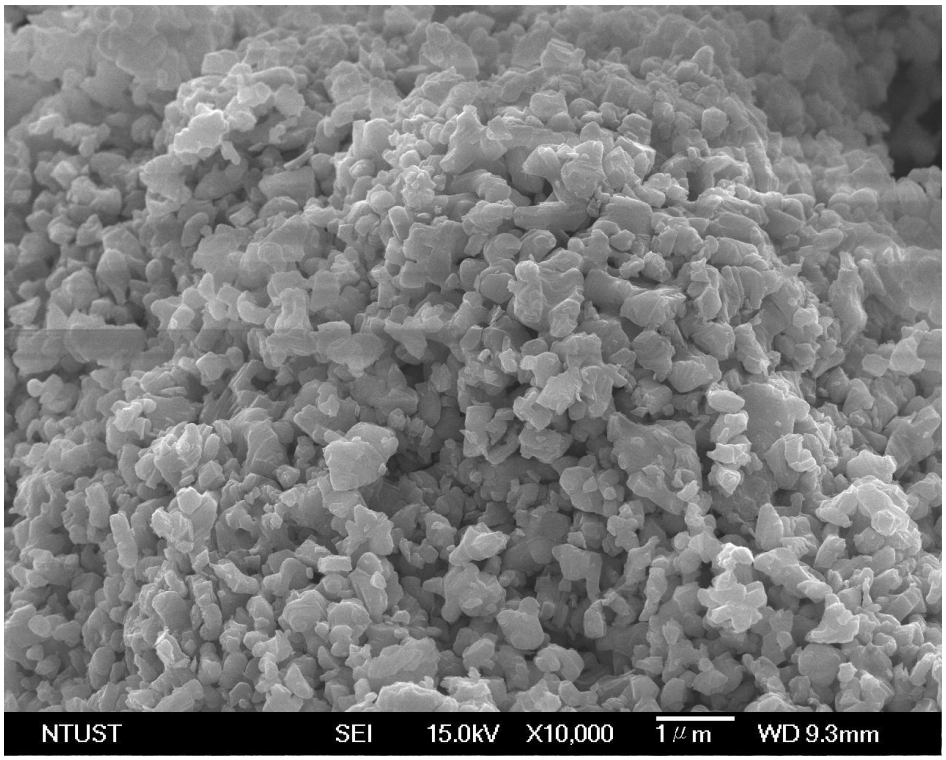
This sample has an almost pure phase $CuFeO_2$ structure, except for a few unknown minor peaks.

2. UV- visible light spectrum



$CuFeO_2$, from this diagram, we can see that its' wavelength absorbance is wide enough to cover the entire visible light range. Although it's aborbance isn't relatively strong; however, due to its' wide range of absorbance, it's a potentially efficient photocatalyst.

3. Scanning Electron Microscopy (SEM)



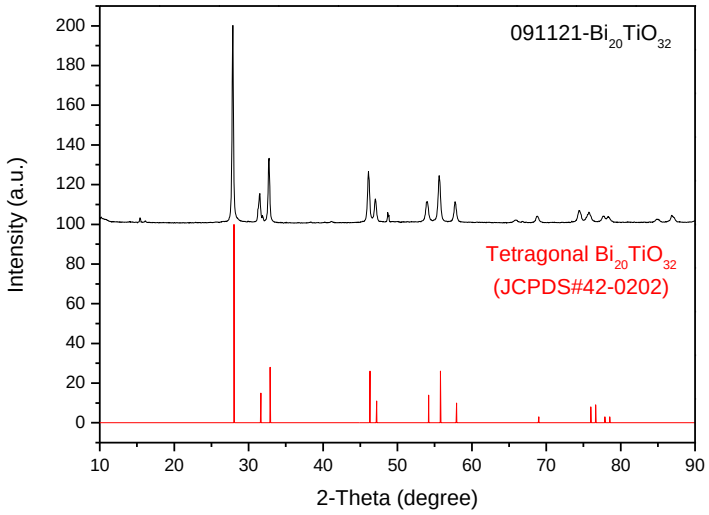
This is the surface of the $CuFeO_2$ photocatalyst. The grain size is large, and the crystalline structure is clear.

4. Results:

A $CuFeO_2$ pure phase photocatalyst is successfully conducted. The absorbance wavelength matches its' band gap value and the visible light wavelength range.

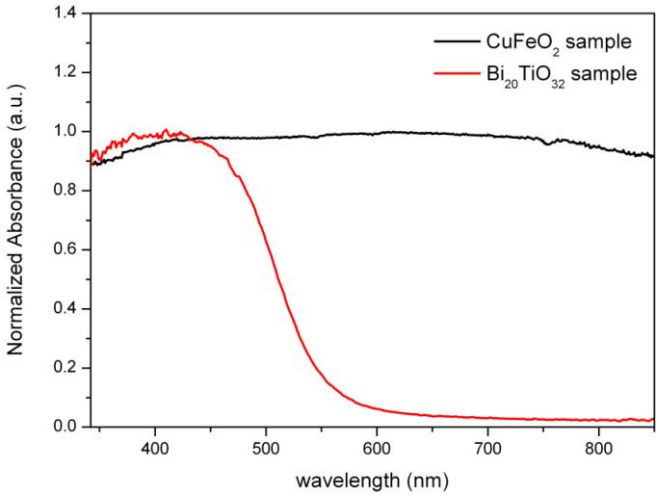
II. $Bi_{20}TiO_{32}$

1. XRD Analysis



For the $Bi_{20}TiO_{32}$ catalyst, we have reached a pure phase photocatalyst. Therefore, sample 091121-$Bi_{20}TiO_{32}$ is being used for further study of this catalyst.

2. UV- visible light spectrum

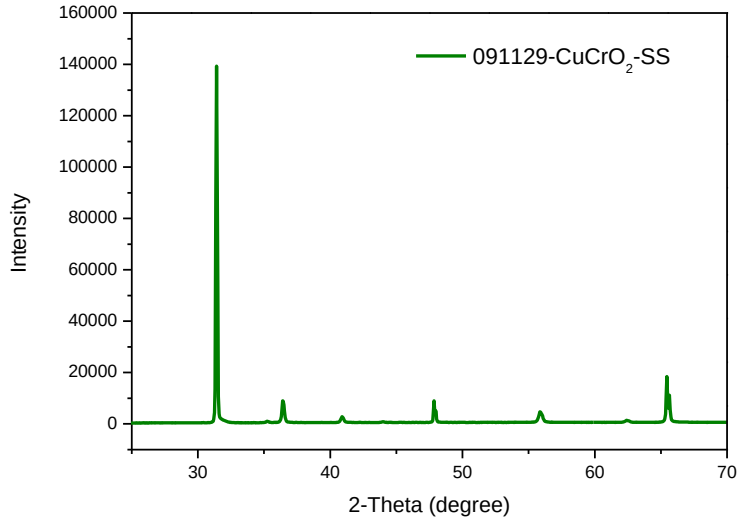


3. Results

Bi20TiO32 is being succesfully conducted, and has a perfect crystanillity. While its' wavelength absorbs visible light range, it has strong absorbance of 400nm visible light.

III. $CuCrO_2$

1. XRD Analysis

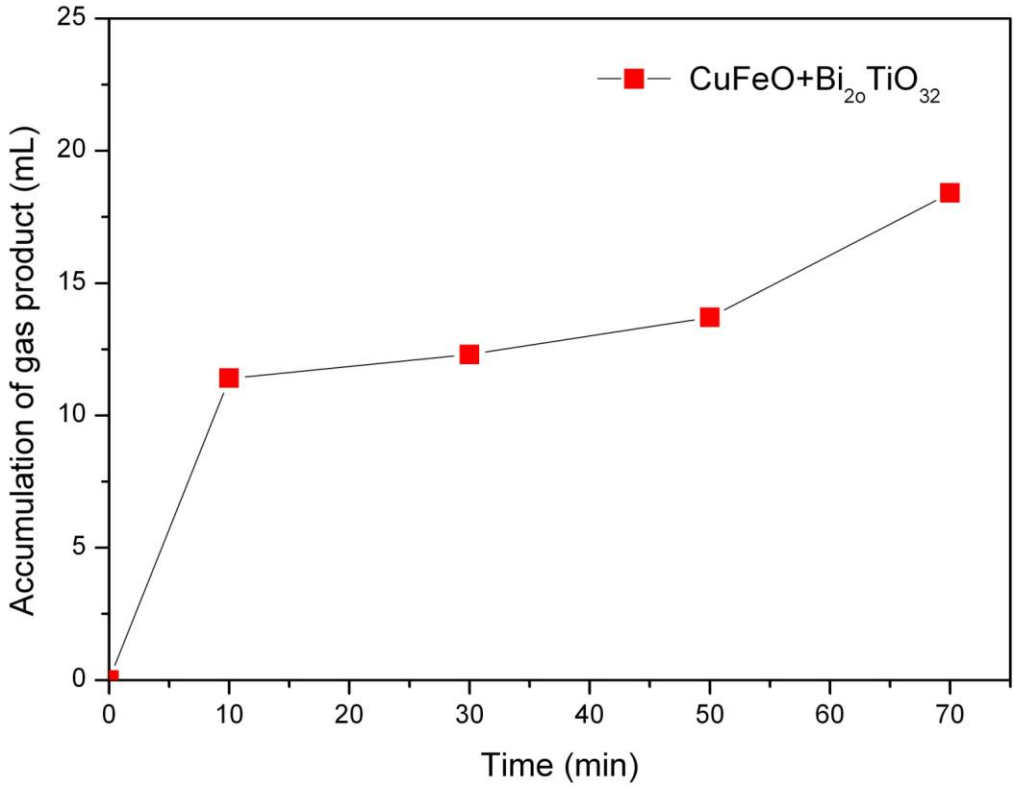


2. Results

The result was unsuccessful, and we couldn't analyze the XRD diagram. We believe that the reason of failure is due to the furnace. For the calcination has to be at 1160℃, which is around the maxima of the furnace, we belive that it is a curical reason why the CuCrO2 catalyst isn't pure phase.

IV. Test on PEC Device

1. Hydrogen Evolution of $Bi_{20}TiO_{32}$ / $CuFeO_2$ junction



The hydrogen evolution diagram of the Bi20TiO32 / CuFeO2 junction for 70 minutes, and the results was shocking. The hydrogen that is produced is 18.4 ml.

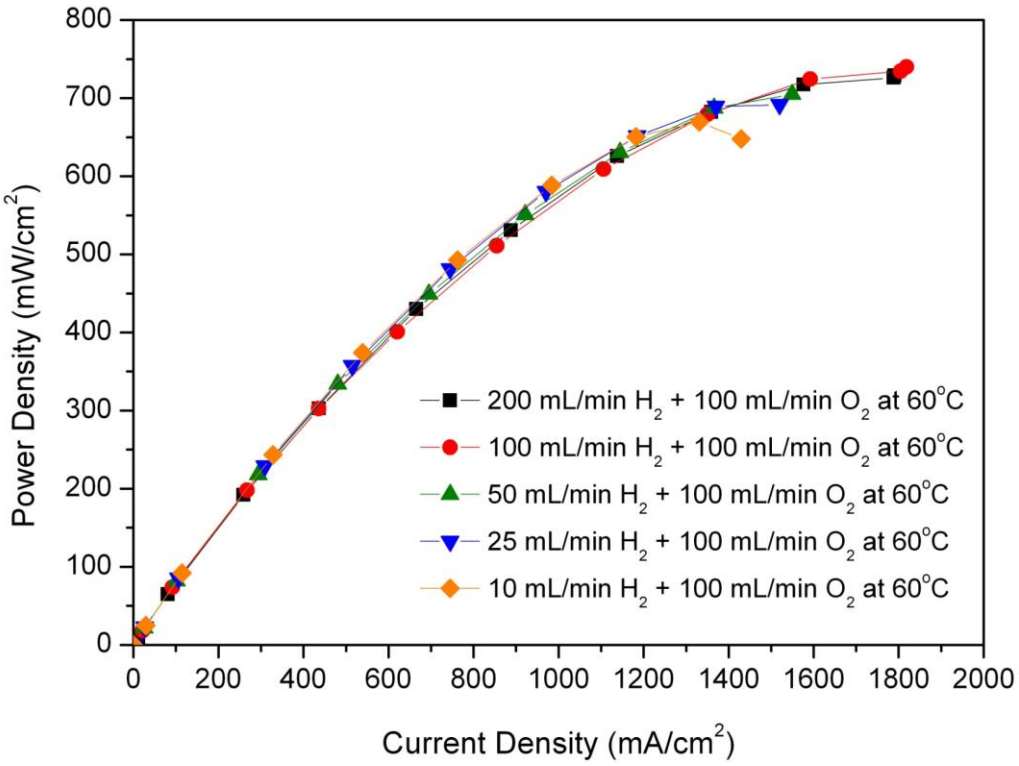
The catalyst amount of CuFeO2 is 0.0126 g, meaning that the hydrogen evolution is at 586.6 ml/ hr per gram, which is 8.38ml/min per gram!

B. Fuel Cell

I. Parameters effect on Fuel Cell

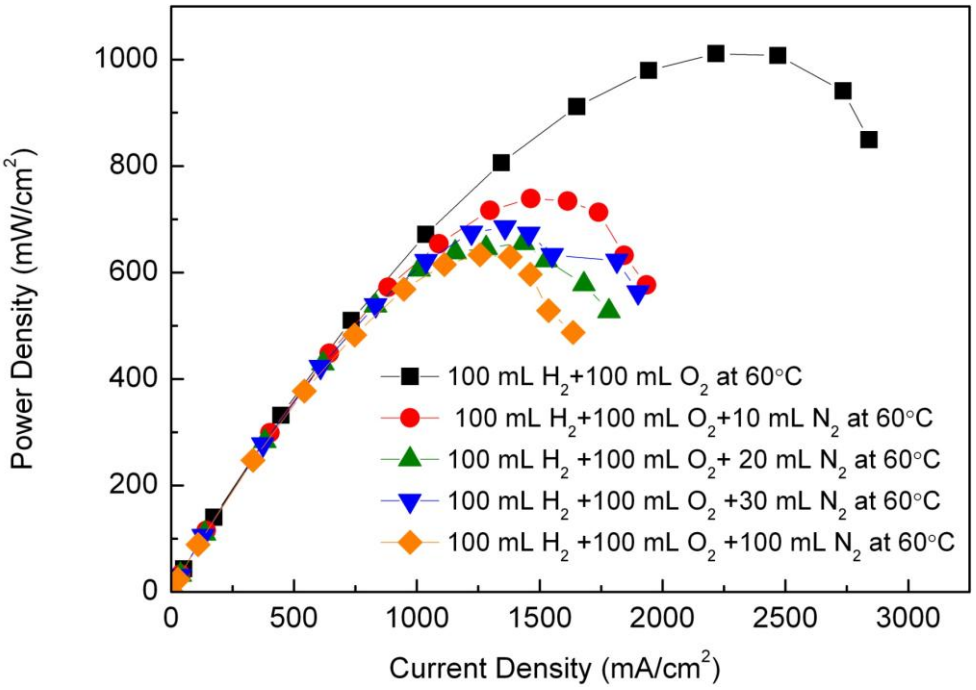
1. Parameters:

(1) Temperature



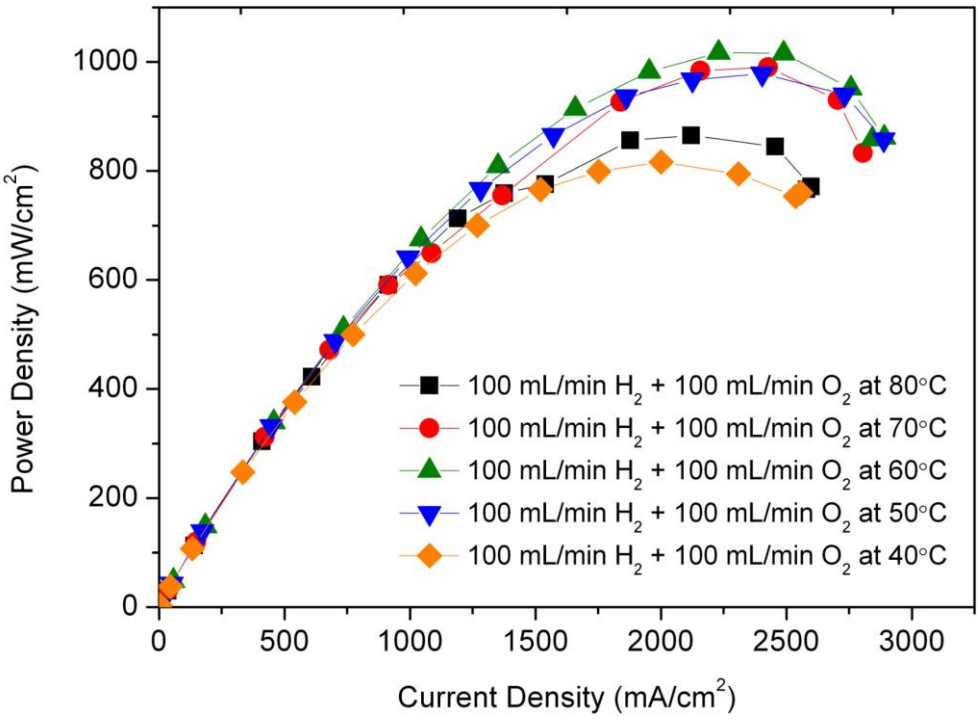
From this graph, it can be told that at 60 ℃, the current density is the strongest; while at 40℃, 50℃, and 80℃ the performance is relatively terrible. At 60℃, it has a maximum power density of 1.12W/cm2.

(2) Nitrogen added ratio



The amount of nitrogen ratio that has the best performance is not adding nitrogen to hydrogen at all. From the diagram, it shown the case when the more nitrogen is being added, the worse the performance of the fuel cell is.

(3) Different amount of Hydrogen

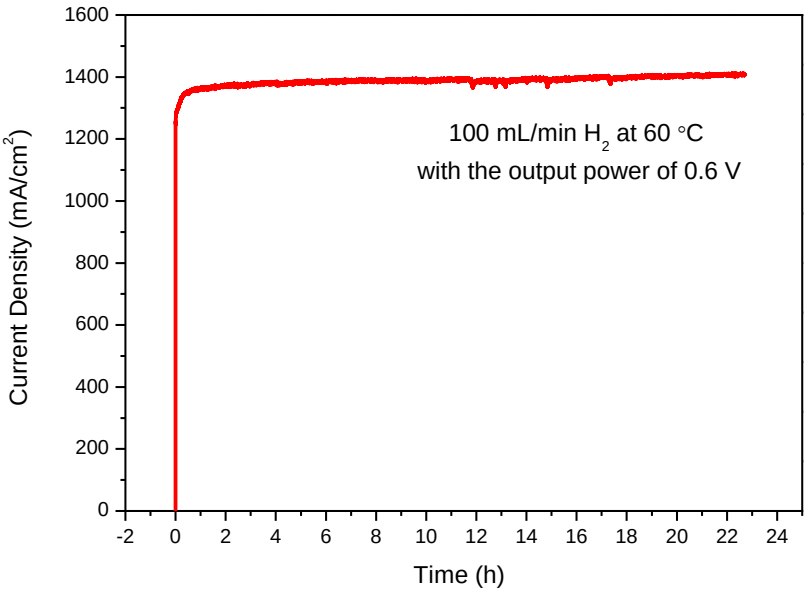


The amount of hydrogen that has the best performance is 100mL / min, while the least amount of hydrogen that is needed to drive a fuel cell with a reasonable amount of power density produced is 50mL/min.

(4) Discharge curve of best condition

Discharge curve with all the best conditions which are the following:

Parameters	Condition
Temperature	60℃
Nitrogen Ratio	0%
Amount of Hydrogen	100mL/min



The voltage is set at 0.6V, since it is the lowest voltage of engine that is designed especially for PEMFC.

Conclusions

- The novel photo-catalytic water-splitting system is functional and produces 8.41ml/min of hydrogen

Photocatalyst	Hydrogen Evolution (μ -mol h^{-1})
$Pt/SrTiO_3 – BiVO_4$	15
TiO_2	568
$NaTaO_3$: La	19,800
$CuFeO_2 – Bi_{20}TiO_{32}$	**20,574**

Cited from Chem Soc Rev 2009, 38, 253-278

- Catalyst $CuFeO_2$ and $Bi_{20}TiO_{32}$ are both active under visible light, which is important when sun light is consisted of 9% UV light, 91% of visible light and IR.
- From Gas Chromography(GC) results, it is indicated that the gas produced from the CuFeO2/Bi20TiO32 junction and reactor is consisted of xx% hydrogen and xx% of …
- Production of $CuFeO_2$ is found to be most stable at temperatures 1015 – 1090 ℃ under air atmosphere.
- The combination of the two system is functional, and can be further enhanced for future use, having a 1.3A of energy produced at 0.6V, which is equivalent to 0.78W of power.
- Discussions on the performance of various parameters set on the fuel cell has been done. A result of 100ml of hydrogen, 60 ℃ and no nitrogen included is the best condition of the tested fuel cell

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