Photoelectrochemistry of Solar Energy Capture and Conversion by Using Particulate Silicon Carbide Semiconductor

By

Mohd Azlan B Mohtar (12673)

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

Supervisor: AP. Dr. Bambang Ariwahjoedi

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CERTIFICATION OF APPROVAL

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Approved by:

____

AP. Dr. Bambang Ariwahjoedi

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Mohd Azlan B Mohtar

ABSTRACT

Solar technology is one of the alternative for future sustainable energy system. However, to capture and convert solar energy into electrical energy prove to be huge challenge. When the first photoelectrochemical (PEC) phenomena were observed back in 1839, numerous research have been done to determine the best semiconductor material suit for the process. This research focus on the preliminary investigation of photoelectrochemical cells using silicon carbide (SiC) as semiconductor material and observe the effect of electrolyte used. SiC is extracted from a conventional disk type sand paper and undergo series of washing and cleaning using toluene and hexane. Material characterization is done using Field Emission scanning electron microscopy (FESEM) and later tested using X-ray Diffusion (XRD) to monitor its composition. Several modes of experiment conducted to observed cells performance in term of voltage and current produce with or without sunlight illumination. The experiment is conducted under ambient condition with two difference electrolytes tested which are 0.1 M Sodium Sulfite (Na_2SO_3) solution and 0.1 M Potassium Hydroxide (KOH) solution. General findings from the experiment and material characterization process is presented in this paper.

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Many thank to our Final Year Project Coordinators, for their unlimited contributions success in providing the students with guidelines and seminars to enlighten hopes of confidence. Not forget to thank all lab executive and technicians as their willingness to provide the facilities and entertain our demand during conducting the project.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of study

The current energy demand had increase significantly to compensate with the growing society and increase in industrial sector. This scenario can be observed in the following figure by looking at the current energy consumption data. Here, the rise in energy consumption is primarily contribute by the increased in fossil fuel use such as oil and natural gas.

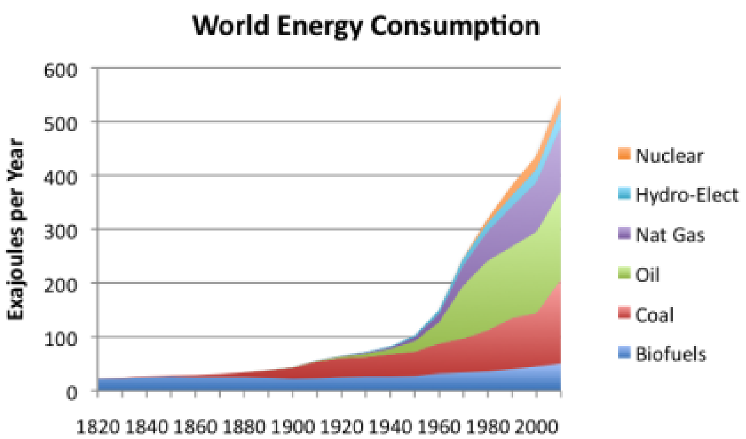

FIGURE 1.1: World Energy Consumption by Source, Based on Vaclav Smil estimates from Energy Transitions: History, Requirements and Prospects together with BP Statistical Data for 1965 and subsequent

The use of fossil fuel in producing energy have a huge drawback to the society and environment especially. Instead of producing huge amount of energy, by product produce contain carbon dioxide can contributes to global warming. On the other hand, other greenhouse gases produce worsen world's climate. Based on the figure, the use of alternative source such as hydroelectric and nuclear energy to fulfil the demand is a novel idea in reducing carbon dioxide produce.

The world demand in fossil fuel will come an end, thus sustainable energy production process must be developed for the benefit of mankind. One of the alternative that will be the key to be used as sustainable energy system is solar generation technology.

Total solar energy received by earth surface every day is enough to support world's energy demand for 16 years at present rates of utilization [1]. However, to harness this potential as reliable and economic carbon-free sources of electricity and fuels still remains a huge challenge. Today, Solar energy technologies include solar heating, solar photovoltaics, solar thermal electricity and solar architecture in which can make considerable contributions to solving some of the most urgent energy problems the world now faces. On the other hand, a new technology such as photoelectrochemical cell emerges to challenge current device which based on the unique properties of matter at nanoscale.

Current available technology used silicon based photovoltaic (PV) technology to produce electricity. However, the price is still too high to be competitive with fossil fuels. Thus, the development of photoelectrochemistry offer a low cost and more robust technology in converting solar into electrical energy.

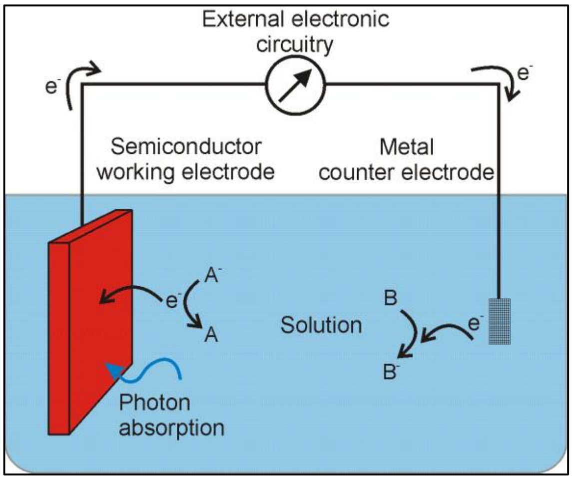

FIGURE 1.2: Diagram of a Photoelectrochemical Cell

Basic concept of a photoelectrochemical cell is shown in Figure 2. When light (photon) is absorbed by the semiconductor electrode, electrons are excited to a higher energy level. The process generate potential difference between electrode will allow the electron to flow through external circuit which produce electrical power. Simultaneously, redox reaction proceeds at both semiconductor and counter electrode to allow no net chemical change occurring in the cell [2].

Photoelectrochemical (PEC) phenomena was first discovered by Becquerel in 1839, who observed a photocurrent which is a flow of electrons upon illumination with light, between two electrodes immersed in solution [2]. The discovery leads to the application of PEC in various cell types such as extremely thin absorber (ETA), organic solar cells, Dye-sensitized solar cell or Gratzel cell, and regenerative solar cells [1].

1.2 Problem Statement

The current demand for energy consumption had increased as world populations continue to increase. The trend forces power plant to increase production capacity in order to cope with the market growth. Oil and natural gas remained the world's largest energy source while coal had posted a growing role in the energy production industry due to its large economic margin. Global warming emissions resulting from energy production is a serious environmental issue. CO_2 and greenhouse gas emission from fossil fuel and coal is the main contributor to this climate crisis.

Renewable energy comes from natural resources such as sunlight, wind, rain, tides, and geothermal provides sustainable energy source with relatively low emission level. In Malaysia, the climate suitable to harness the sun energy as the country received a constant sunlight throughout the year. Thus, the development of LOW cost solar energy conversion using photoelectrochmical cells is highly recommended.

1.3 Objectives

The main objectives of this study are:

i. To investigate the performance of photoelectrochemical cells using silicon carbide as semiconductor material.
ii. To study the effect of different solution (electrolyte) used to enhance the ability of the cells.

1.4 Scope of Study

The study focus on development of photoelectrochemical cells to covert solar into electrical energy, subject should be tested with the following parameter.

i. Used of silicon carbide as semiconductor material for photo electrode in the cells. The study limited only to determine the presence of potential difference and current flowing through the external circuit.
ii. Electrolyte used limited to sodium sulfite and potassium hydroxide where the variation in concentration should be tested.

1.5 Relevancy of the project

With the dependent on fossil fuel as the main source of energy rise huge concern in term of environmental issue and price. The preliminary study on photoelectrochemistry act as a stepping stone in discovering renewable energy source which will be commercialize in the future. The technology offers low production cost with the guarantee of better and more robust system.

CHAPTER 2

LITERATURE REVIEW

Common photovoltaic (PV) solar cell used semiconductor solid state contact, however, it is possible to used semiconductor and electrolyte contact in order to convert light energy into electric power [2]. However, in semiconductor electrochemistry, a charge transfer from the electrode to the electrolyte has to take place in addition to the current flow through an external circuit. This charge transfer can be utilized by inducing a battery reaction. In photoelectrochemistry, a direct conversion of solar into chemical energy is possible by having redox reaction initiated by sunlight.

At the semiconductor material and electrolyte, a space charge region is formed where contact formation compensates the electrochemical potential differences of electrons. It is assume that the band edges of semiconductor at the interface is only dependent on the solution pH level instead of potential (Fermi level) of the electrode or the electrolyte. Upon illumination, electrons in the conduction band of the semiconductor reach the electrode surface and can reduce redox couples whose redox potentials are located below the conduction band. On the other hand, Holes in the valence band can oxidize species with a redox potential more negative than the band edge of the valence band at the interface.

Semiconductor has been used as electrode material in photoelectrochemical cell due to its band gap energy, E_g falls in the range of 1-3 eV. It is well overlaps within light spectrum received by the sun [1]. High energy photon will be absorbed by semiconductor materials which lead to electron excitation state to generate electrical power upon illumination. For the process to happen the photon energy, *hv* must be greater than semiconductor band gap energy, E_g [3]. In recent study done by US

National Renewable Energy Laboratory (NREL) has identified gallium indium phosphide ($GaInP_2$) as a very promising semiconductor material in photoelectrochemical cell. However, high production cost force the study to focus on using silicon carbide (SiC) semiconductor which is believed to have efficiencies of the order of 7% based on laboratory test [4]. Figure below shows intensity of solar radiation and semiconductor band gap energy.

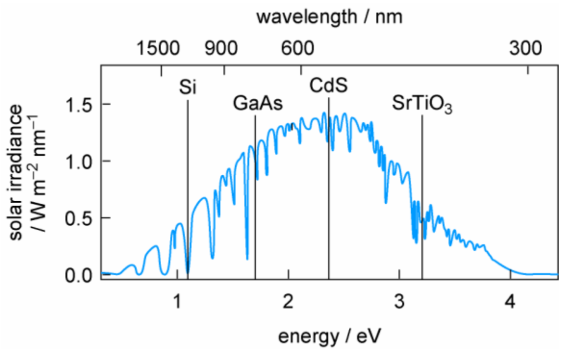

FIGURE 2.1: Solar irradiance at the earth surface and band gap energy for respective semiconductor.

SiC semiconductor has a limited its solar absorption capability due to its large band gap energy (> 3 eV). However, it is believed that the limitation can be overcome by sensitization of SiC with synthetic dyes as well as narrow band gap semiconductor [4]. One method to enhance SiC performance is by etching process [5] where uses strong acid to cut into unprotected part of the metal surface. This process applied for n-type semiconductor (photo-anodic etching) to create a depletion layer to separates electron and holes produced by illumination [6].

Photoelectrochemical cells required an electrolyte containing an appropriate redox couple to drive charge transfer. In ideal regenerative photoelectrochemical solar cells, the light illumination does not change the electrolyte composition throughout the process and the only product is electrical power [7].

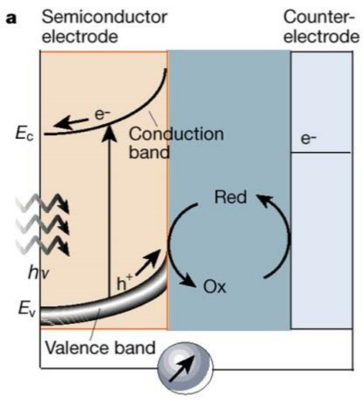

FIGURE 2.2: Carrier generation under illumination at the semiconductor/liquid interface

The electron excitation states during absorption of photons have lifetimes of limited duration. Without a mechanism of charge separation, their energy would be lost through relaxation or recombination [7]. On the other hand, photoelectrochemical cells can also generate electrochemical energy which provides energy storage capability to the cells. This helps to ensure continuous output insensitive to daily variations in light illumination.

In general regenerative photoelectrochemical cell consist of a photo-electrode which having a semiconductor material. It is possible to construct the cells with two photo-electrodes and a suitable redox couple, hence increase the output voltage. Meanwhile in practical, the ohmic resistance of the cell should be minimize to avoid internal power loss [1].

Photoelectrochemical cell used for solar photon conversion usually designed to produce electrical energy and/or solar fuel. To evaluate the performance of particular cells, the energy conversion efficiency is calculated using following equation at their maximum power point

$$\eta_{mp} = \frac{i_{mp}}{E_0^S} V_{mp} \quad (2.1)$$

Where;

η_{mp} = energy conversion efficiency
i_{mp} = maximum power photocurrent density
V_{mp} = maximum power voltage
E_0^S = solar irradiance

On the other hand, the device performance also determined by the fill factor, η_{fill}. Higher value prefers better device quality.

$$\eta_{fill} = \frac{i_{mp}}{i_{sc}} \frac{V_{mp}}{V_{oc}} \tag{2.2}$$

η_{fill} = Fill factor
i_{mp} = maximum power photocurrent density
i_{sc} = short − circuit photocurrent density
V_{mp} = maximum power voltage
V_{oc} = open circuit voltage

Several studies have been done to determine the performance of regenerative photoelectrochemical cells. Material used for electrodes varies from metal oxides, group IV compounds and also multi junction electrodes. For metal oxides electrodes using TiO_2 register energy efficiency of 0.6% as reported by Mavroides et al. (1975). Cells using silicon as an electrode gives 12.1% efficiency in CH_3OH solution, reported by Rosenbluth et al. (1984). The most efficient regenerative photoelectrochemical cell is using multi junction electrodes of AlGaAs/Si in HCL solution having 19.7% efficiency as reported by Litch et al. (1998)

CHAPTER 3

METHODOLOGY

3.1 Project Flow

Project flow is a graphical representation of the order by which a sequence of activities is created to achieve the desired output. Figure 3.1 below shows the flow diagram throughout this Final Year Project.

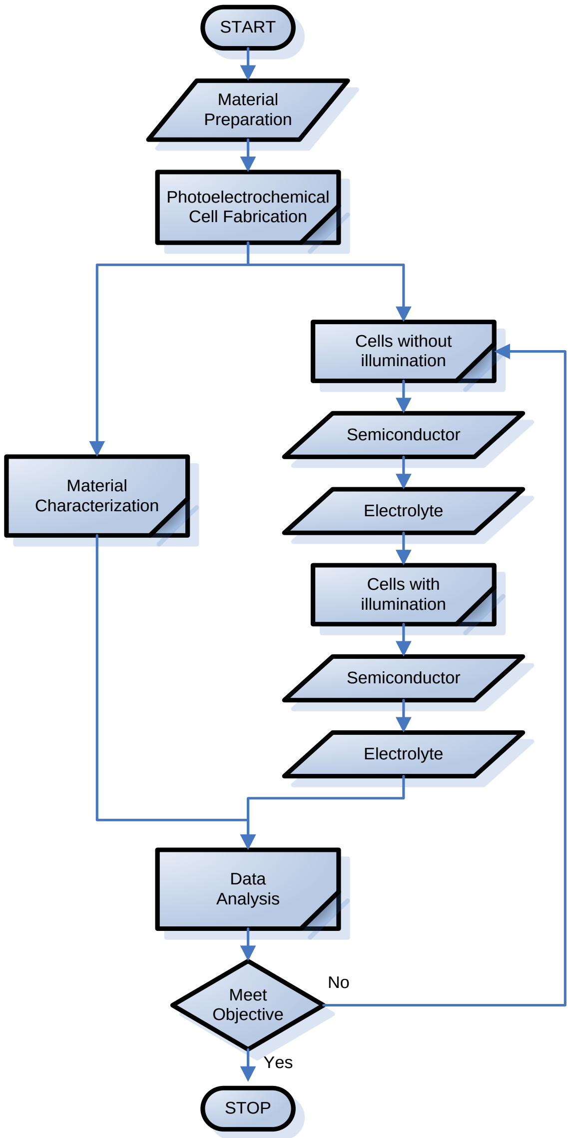

FIGURE 3.1: Project flow diagram

3.2 Experimental Approach

3.2.1 Raw Material and Chemical Needed

TABLE 3.1: List of Chemical and Apparatus

Chemical	Apparatus
Potassium hydroxide, KOH	Beakers
Sodium Sulfite, Na_2SO_3	Wire
Benzene	Aluminium Foil
Toluene	Potential Meter
Thinner (Conventional Solvent)	
Silicon Carbide	

3.2.2 Experiment Setup

The experiment required fabrication of photoelectrochemical cell prototype as figure below.

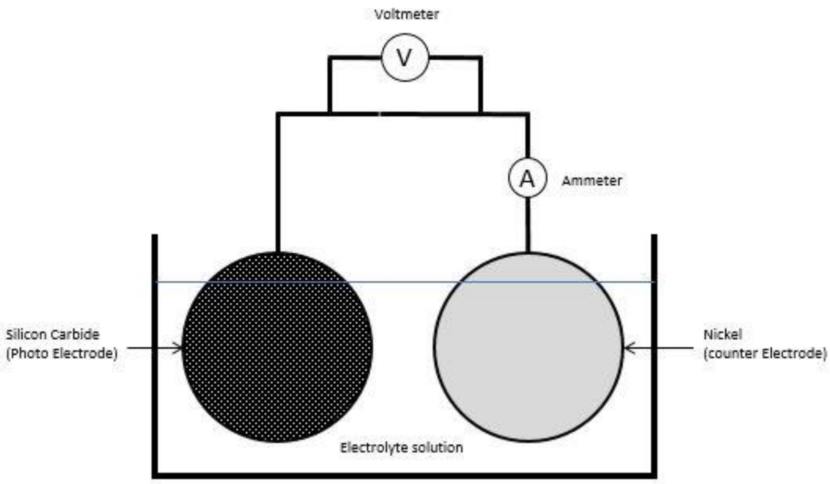

FIGURE 3.2: Electrochemical Cell experiment setup

The setup consist of a photo electrode (Silicon Carbide) connected through external circuit to the counter electrode in the same electrolyte solution. To observe any electrical energy produce during illumination process, potential meter placed at the external circuit to measure voltage and current produced.

3.2.3 Modes of Experiment

The experiment will be carried out with the used of silicon carbide as semiconductor material while nickel (coin) act as the counter electrode. Initially the cell will be tested with nickel placed in both electrode for control parameter. Difference electrolyte such as potassium hydroxide and sodium sulfite will be used throughout the experiment with and without illumination of light, thus data collected based on output voltage and current against time flowing through external circuit. Table below shows summary of experimental modes taking place.

TABLE 3.2: Experimental Modes

No	Semiconductor Electrode	Counter Electrode	Electrolytes	Illumination	Remark
1	Nickel	Nickel	Potassium hydroxide, KOH	Yes	Control Experiment
2				No	
3			Sodium Sulfite, Na_2SO_3	Yes	
4				No	
5	Silicon Carbide, SiC	Nickel	Potassium hydroxide, KOH	Yes	
6				No	
7			Sodium Sulfite, Na_2SO_3	Yes	
8				No	

3.2.4 Material Characterization

The experiment require used of other equipment which available in the university for material characterization of silicon carbide semiconductor. Equipment used listed below.

- X-Ray Diffraction (XRD)
  - Non-destructive technique that reveals detailed information about the chemical composition and crystallographic structure of natural and manufactured materials.
- Field-Emission Scanning Electron Microscope (FESEM)
  - Taking images of a sample surface by raster scanning over it with a high-energy beam of electrons.

3.3 Milestone for Final Year Project (FYP) I

TABLE 3.3: key milestone for FYP I

No	Descriptions	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Title															
2	Preliminary Research Work and Literature Review															
3	Submission of Extended Proposal Defence							●								
4	Preparation for Proposal Defence															
5	Proposal Defence Oral Presentation															
6	Detailed Literature Review															
7	Preparation of Interim Report															
8	Submission of Interim Draft Report														●	
9	Submission of Interim Final Report															●

3.4 Milestone for Final Year Project (FYP) II

TABLE 3.4: key milestone for FYP II

No	Description	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue															
2	Submission of Progress Report				●											
3	Project Work Continue															
4	Seminar															
5	Project Work Continue															
6	Poster presentation												●			
7	Submission of technical paper														●	
8	Submission of Dissertation														●	

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Material preparation

4.1.1 Silicon carbide extraction

The process started with the selection of silicon carbide disk type sand paper available in the market. In this experiment, sand paper having grit size of 120 is selected because the silicon carbide material on that particular disk surface can easily extracted compared to the neighboring disk type (in this case disk number 50, 80 and 100). Figure 4.1 below shows the silicon carbide disk type sand paper used in this experiment.

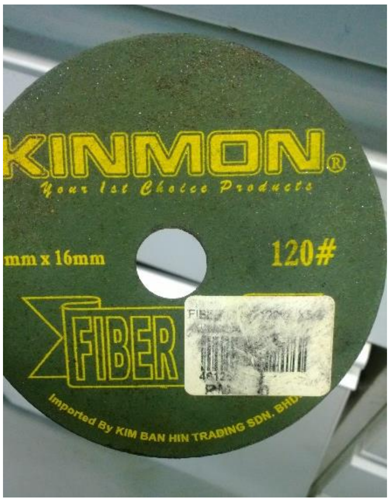

FIGURE 4.1: Silicon Carbide Disk Type Sand Paper

The extraction is done by letting the disk remain in conventional thinner solution to loosen silicon carbide particle from the surface. After few days, the compound is removed using spatula and the result can be observed from figure 4.2 below.

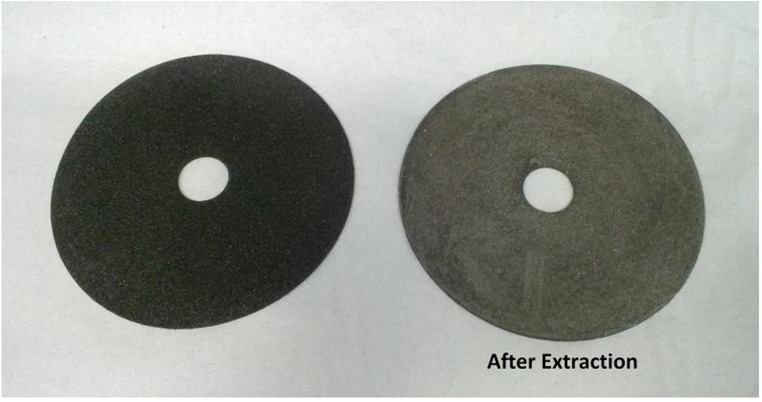

FIGURE 4.2: Sand Paper Before and After Extraction

The extracted compound is undergo series of filtration and washing with both hexane and toluene solutions to remove impurities. Figures 4.3 below shows the filtration and washing process.

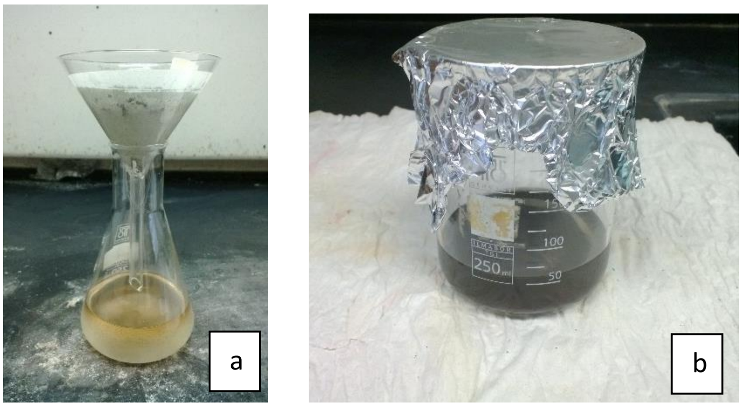

FIGURE 4.3: (a) Filtration and (b) Washing Process

Finally the extracted silicon carbide compound is dried and the final product shown in the figure 4.4 below. Sample weighing process recoded the sample weight of 4.23 gram.

FIGURE 4.4.: Silicon Carbide Powder

4.2 Material characterization

Silicon carbide is a compound composed of silicon and carbon with a chemical formula of SiC. It is one of the hardest known materials with a Mohs scale hardness of 9+. It is occurs naturally as the mineral rock which is extremely rare and can only found in tiny quantities in a limited number of locations. All of the silicon carbide sold as an abrasive is manufactured. It can produced by placing a mixture of coke, sand and sawdust in an electric resistance furnace and heating to a very high temperature. The silicon carbide is then crushed and screened into specific sizes.

In this experiment, silicon carbide particles are extracted from conventional disk type sand paper. Figure 4.5 pictures taken by SEM on sample of silicon carbide. In SEM analysis, the sample will undergo analysis where sample surface is analyzed using an electron. From the data, it show shape of the particles and size distribution.

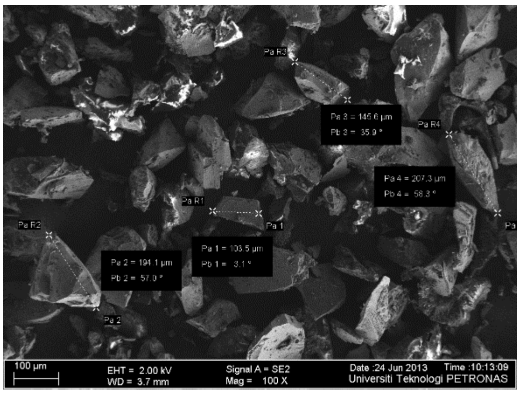

FIGURE 4.5: Silicon Carbide Material with 100 Times Magnification

4.2.1 Shape of the particle

It is obvious from the picture taken by SEM reveals the shape of silicon carbide particles are in angular shape. So, it can deduce that the material is crushed into small particle and put together according to required sizes. On the other hand, the shape reveals no trace of particle growth or crystallization process occur.

4.2.2 Particle size

The silicon carbide components are extracted from conventional disk type sand paper having grit sizes of 120. The numbers used for grit sizes are similar to the numbers used to grade sand paper. Small numbers are used for the coarser grits (larger size particles), and large numbers are used for the finer grits (smaller size particles). Table below shows grit size correspond to particle size in micrometer.

TABLE 4.1: Commercial Grit Size Correspond to Particle Size.

Grit	50	60	80	90	100	120	150	180	200	220	250	270	325	400	500
Particle Size (µm)	297	250	177	166	149	125	100	83	74	68	58	53	44	37	25

Above table suggest the average particle size of silicon carbide used in this experiment is 125 µm. On the other hand, SEM analysis reveals the average particle size is 128.13 µm. The result shows a close average particle size between industrial standard and experimental analysis.

4.2.3 Size distribution

Apart from the average particle size, the distribution of it plays an importance roles in characterizing silicon carbide compound. In this experiment, the particle size is divided in to five range which are less than 50 µm, between 50 µm to 100 µm, between 100 µm to 150 µm, between 150 µm to 200 µm and more than 200 µm. table 4.2 shows the distribution and It is observed that most of the particles distributed in the range of 100 µm to 150 µm.

TABLE 4.2: Particle Sizes Distribution

Range (µm)	< 50	50-100	100-150	150-200	> 200
Amount	1	17	21	10	5

Next, figure 4.6 below shows the particle distribution in bar chart.

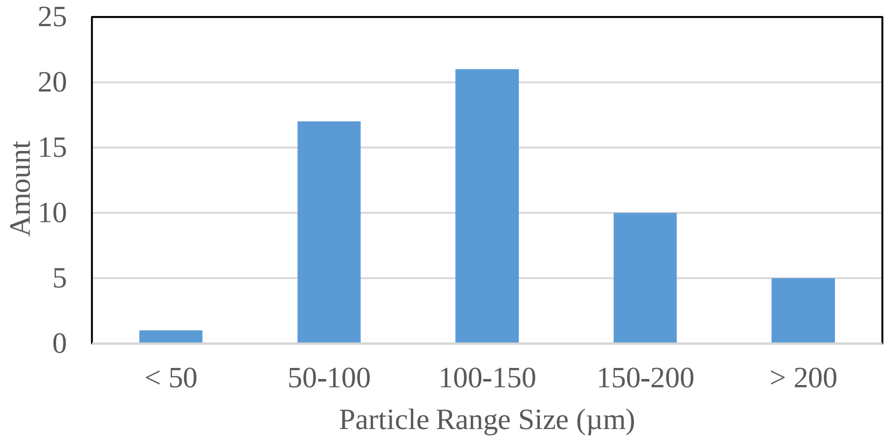

FIGURE 4.6: Particle Sizes Distribution Chart

4.2.4 Composition

The composition of silicon carbide compound is analyze using Energy Dispersive X-ray Spectroscopy or EDX analysis where it is a useful tools widely used for chemical analysis. The intensity of backscattered electrons generated by electron bombardment can be correlated to the atomic number of the element within the sampling volume. Hence, qualitative elemental information can be revealed. Figure 4.7 and figure 4.8 below show the area of EDX analysis followed by their respective composition.

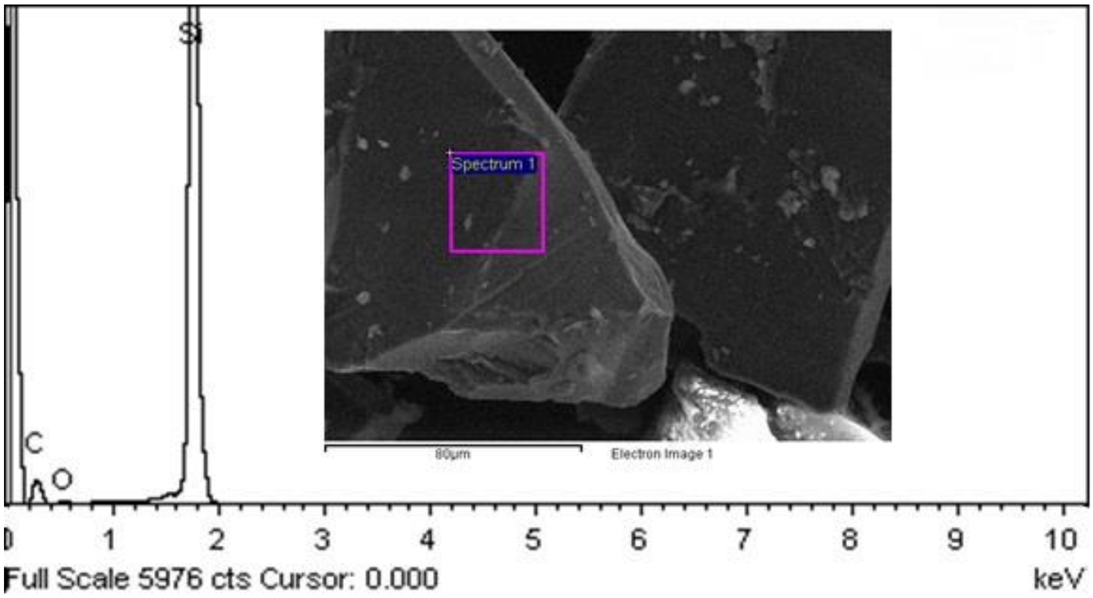

FIGURE 4.7: EDX Analysis Spectrum of Area Indicated in Spectrum 1

Table 4.3 below shows the summary of EDX analysis of spectrum 1 where the major component exist is carbon and silicon. On the other hand, the present of oxygen indicate the silicon had oxidized to become silicon dioxide which commonly found at the external surface of silicon carbide particle.

TABLE 4.3: Element Present In EDX Analysis of Spectrum 1

Element	Weight Percent (Wt %)	Atomic Percent (%)
Carbon	52.22	70.79
Oxygen	3.45	3.51
Silicon	44.34	25.7

On the other hand, analysis for spectrum 2 indicates the present of other impurities such as aluminium and calcium. However, the amount is relatively small so it is neglected since it will not contribute to the interference in later experiment. Figure below shows the EDX analysis and the component exist is summarize in the table 4.4.

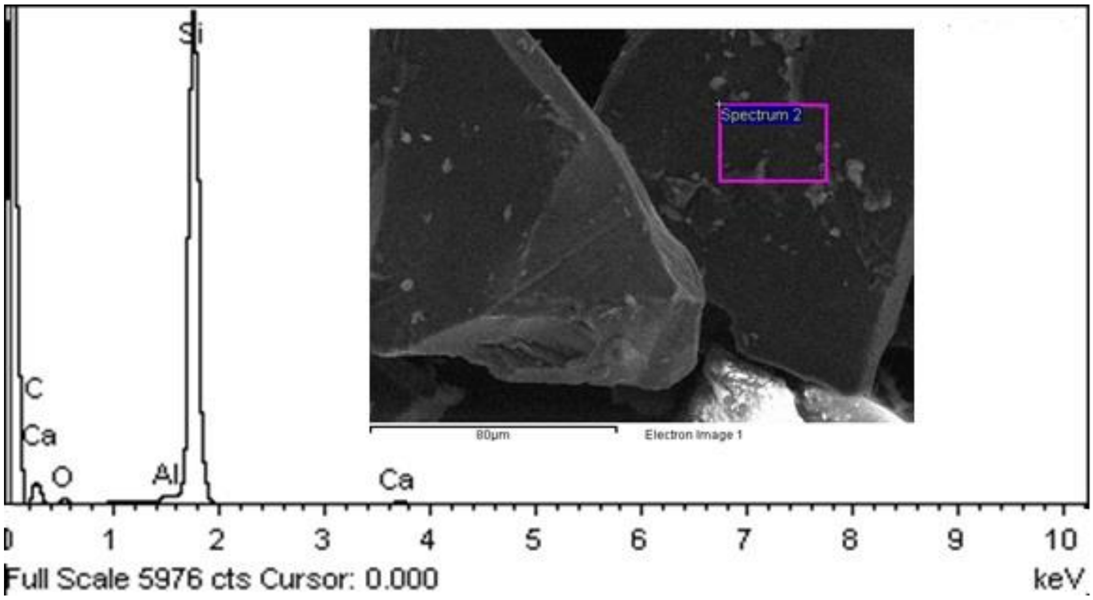

FIGURE 4.8: EDX Analysis Spectrum of Area Indicated in Spectrum 2

TABLE 4.4: Element Present In EDX Analysis of Spectrum 2

Element	Weight Percent (Wt %)	Atomic Percent (%)
Carbon	51.67	69.58
Oxygen	6.07	6.14
Aluminium	0.36	0.22
Silicon	41.53	23.91
Calcium	0.36	0.15

4.3 Experimental Result

4.3.1 Experiment 1 (Nickel/Nickel electrode in KOH without sunlight illumination)

In experiment 1, nickel metal is used as both electrode and counter electrode. It is immersed in potassium hydroxide (KOH) solution 0.1 M. the experiment is conducted without sunlight illumination at room condition for 20 minutes. Table 4.5 shows the experimental data for voltage and current reading against time.

TABLE 4.5: Voltage and Current Reading for Experiment 1

Time (min)	**voltage (V)**	**Current (Times 50μA)**
0	0.001	0.0
2	0.002	0.0
4	0.001	0.0
6	0.001	0.0
8	0.002	0.0
10	0.002	0.0
12	0.001	0.0
14	0.001	0.0
16	0.001	0.0
18	0.002	0.0
20	0.003	0.0

Figure 4.9 and 4.10 shows the voltage and current trend respectively throughout the experiment.

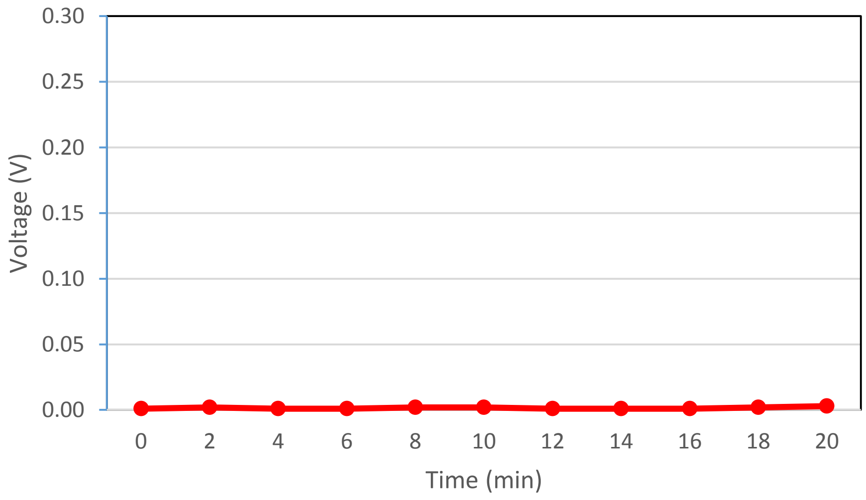

FIGURE 4.9: Voltage reading against time for experiment 1

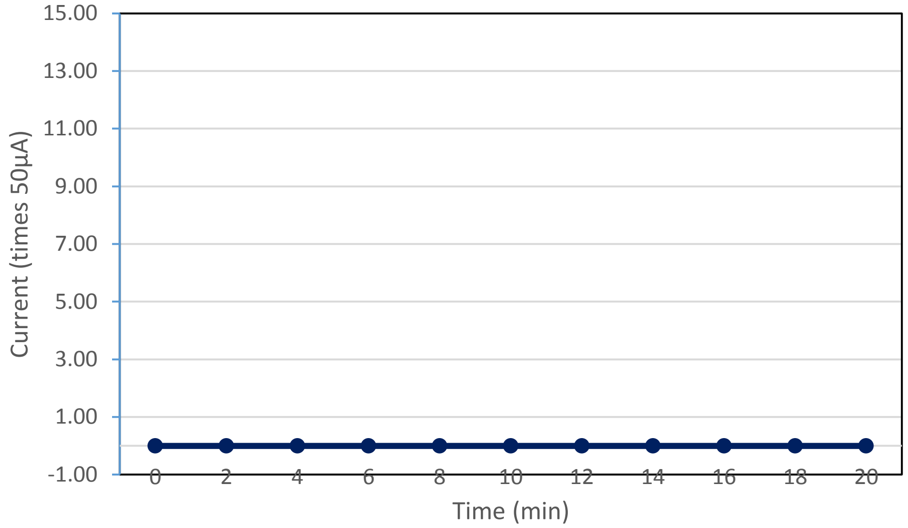

FIGURE 4.10: current reading against time for experiment 1

4.3.2 Experiment 2 (Nickel/Nickel electrode in KOH with sunlight illumination)

In experiment 2, nickel metal is used as both electrode and counter electrode. It is immersed in potassium hydroxide (KOH) solution 0.1 M. the experiment is conducted with sunlight illumination at room condition for 20 minutes. Table 4.6 shows the experimental data for voltage and current reading against time.

TABLE 4.6: Voltage and Current Reading for Experiment 2

Time (min)	**voltage (V)**	**Current (Times 50µA)**
0	0.003	0.0
2	0.004	0.0
4	0.001	0.0
6	0.001	0.0
8	0.002	0.0
10	0.002	0.0
12	0.003	0.0
14	0.001	0.0
16	0.001	0.0
18	0.003	0.0
20	0.003	0.0

Figure 4.11 and 4.12 shows the voltage and current trend respectively throughout the experiment.

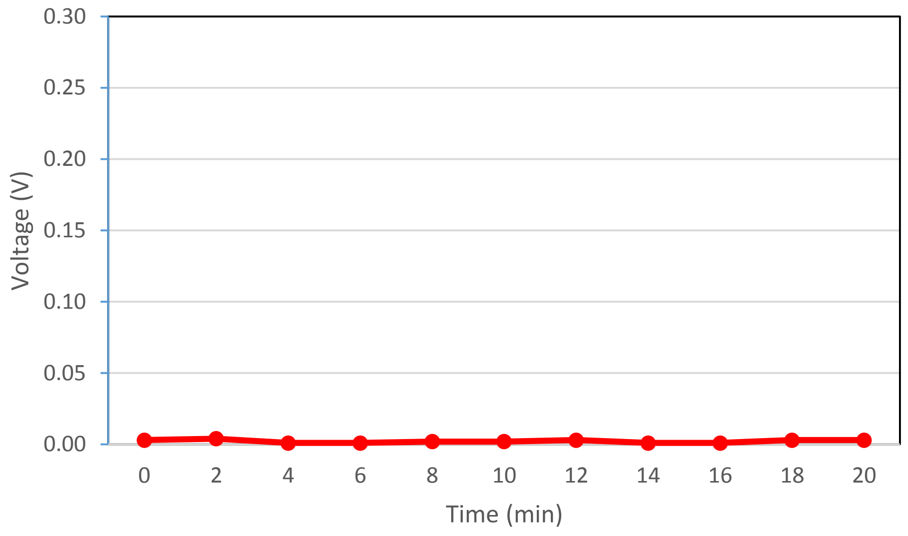

FIGURE 4.11: Voltage reading against time for experiment 2

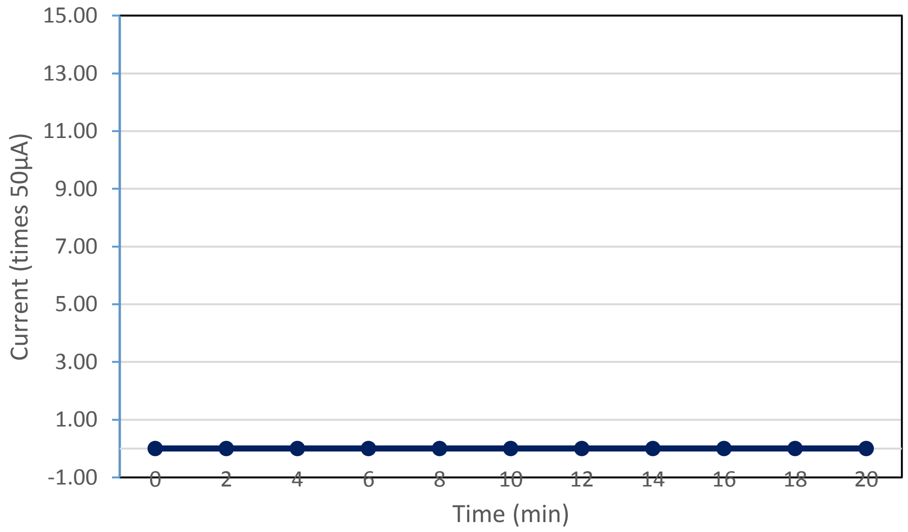

FIGURE 4.12: current reading against time for experiment 2

4.3.3 Experiment 3 (Nickel/Nickel electrode in Na_2SO_3 without sunlight illumination)

In experiment 3, nickel metal is used as both electrode and counter electrode. It is immersed in Sodium Sulfite (Na_2SO_3) solution 0.1 M. the experiment is conducted without sunlight illumination at room condition for 20 minutes. Table 4.7 shows the experimental data for voltage and current reading against time.

TABLE 4.7: Voltage and Current Reading for Experiment 3

Time (min)	voltage (V)	Current (Times 50μA)
0	0.002	0.0
2	0.002	0.0
4	0.001	0.0
6	0.001	0.0
8	0.002	0.0
10	0.002	0.0
12	0.002	0.0
14	0.002	0.0
16	0.001	0.0
18	0.002	0.0
20	0.002	0.0

Figure 4.13 and 4.14 shows the voltage and current trend respectively throughout the experiment.

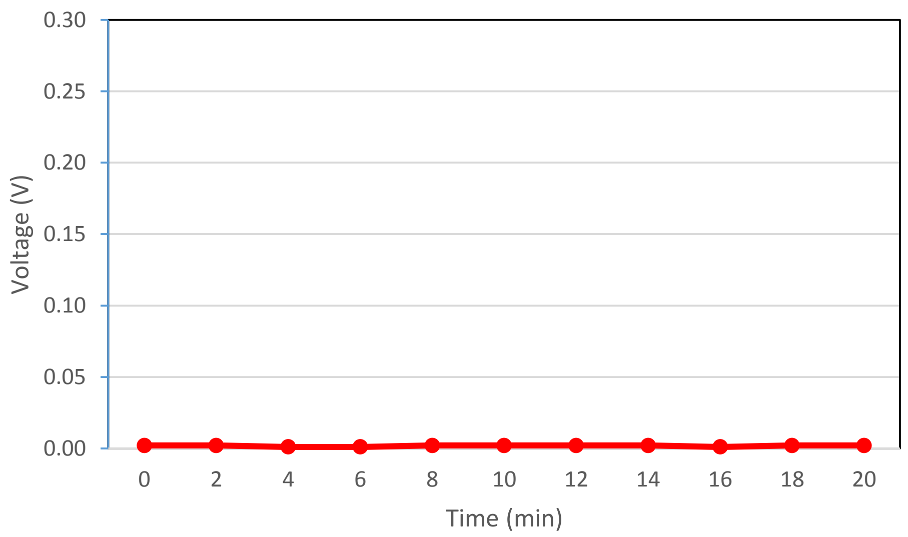

FIGURE 4.13: Voltage reading against time for experiment 3

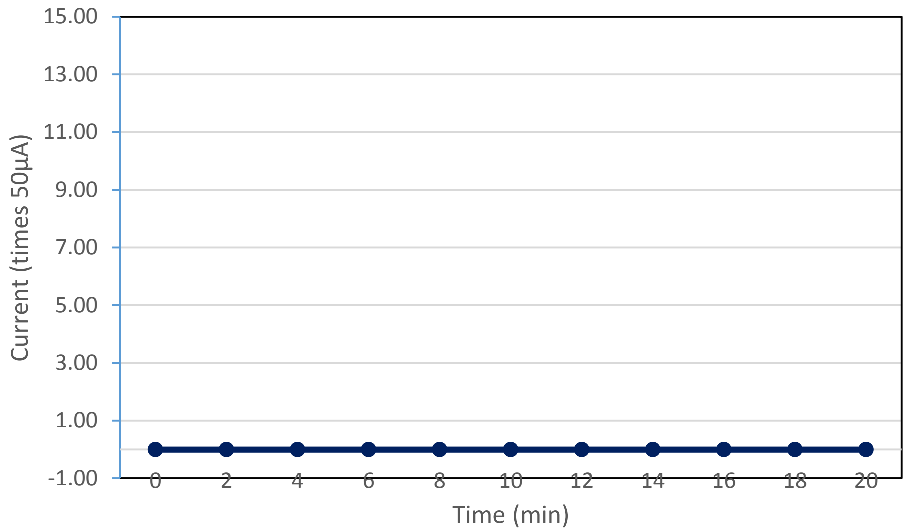

FIGURE 4.14: current reading against time for experiment 3

4.3.4 Experiment 4 (Nickel/Nickel electrode in Na_2SO_3 with sunlight illumination)

In experiment 4, nickel metal is used as both electrode and counter electrode. It is immersed in Sodium Sulfite (Na_2SO_3) solution 0.1 M. the experiment is conducted with sunlight illumination at room condition for 20 minutes. Table 4.8 shows the experimental data for voltage and current reading against time.

TABLE 4.8: Voltage and Current Reading for Experiment 4

Time (min)	**voltage (V)**	**Current (Times 50µA)**
0	0.003	0.0
2	0.004	0.0
4	0.001	0.0
6	0.001	0.0
8	0.002	0.0
10	0.002	0.0
12	0.003	0.0
14	0.003	0.0
16	0.005	0.0
18	0.003	0.0
20	0.003	0.0

Figure 4.15 and 4.16 shows the voltage and current trend respectively throughout the experiment.

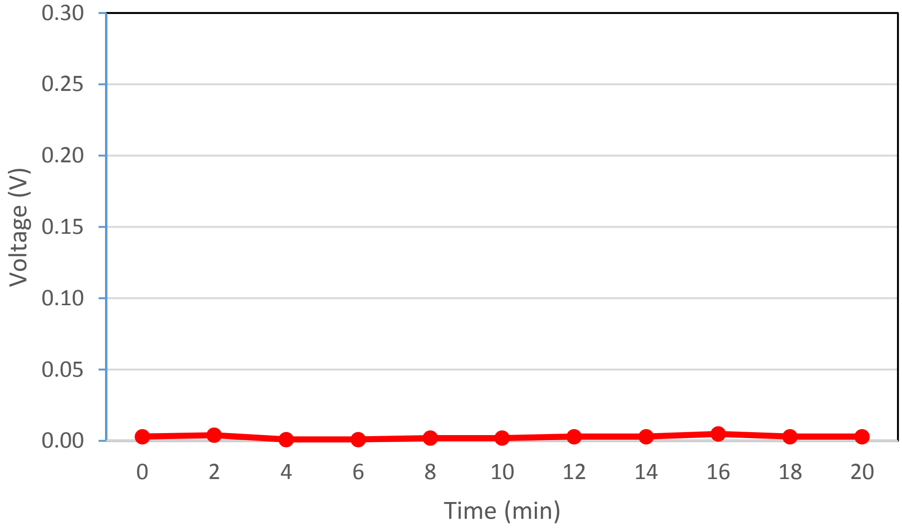

FIGURE 4.15: Voltage reading against time for experiment 4

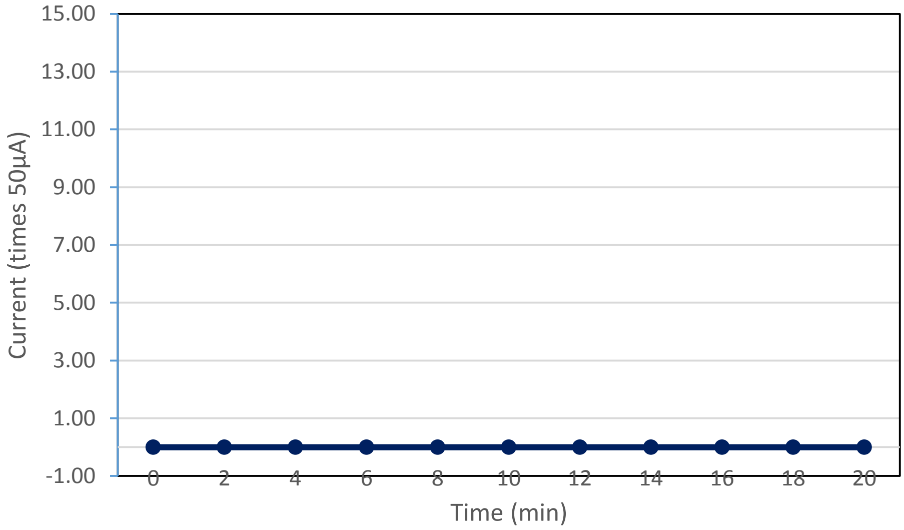

FIGURE 4.16: current reading against time for experiment 4

4.3.5 Experiment 5 (SiC/Nickel electrode in KOH without sunlight illumination)

In experiment 5, silicon carbide (SiC) material is used as semiconductor material while nickel placed at the counter electrode. It is immersed in Potassium hydroxide (KOH) solution 0.1 M. the experiment is conducted without sunlight illumination at room condition for 20 minutes. Table 4.9 shows the experimental data for voltage and current reading against time.

TABLE 4.9: Voltage and Current Reading for Experiment 5

Time (min)	voltage (V)	Current (x50μA)
0	0.0500	0.00
2	0.1255	1.00
4	0.2044	1.00
6	0.2305	1.50
8	0.2429	2.00
10	0.2727	3.00
12	0.2814	4.00
14	0.2831	5.00
16	0.2725	4.00
18	0.2845	6.00
20	0.2785	6.00

Figure 4.17 and 4.18 shows the voltage and current trend respectively throughout the experiment.

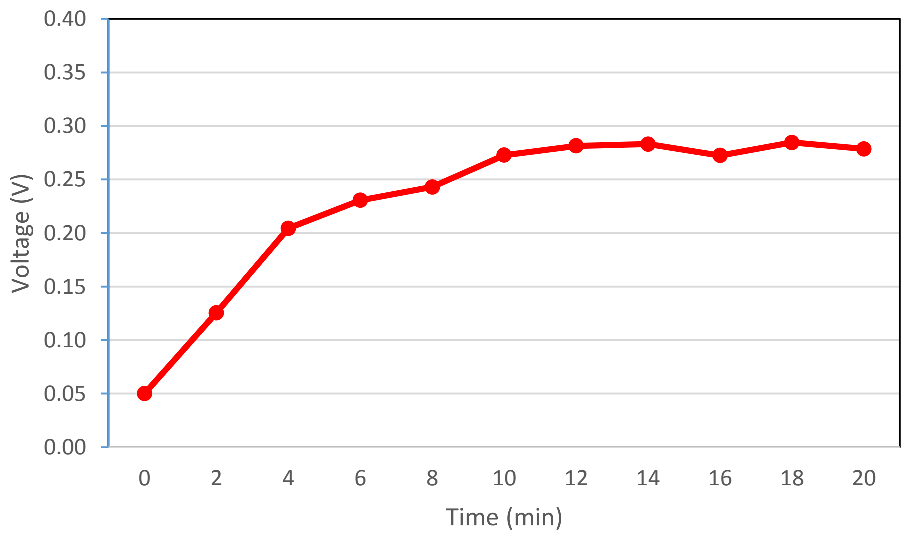

FIGURE 4.17: Voltage reading against time for experiment 5

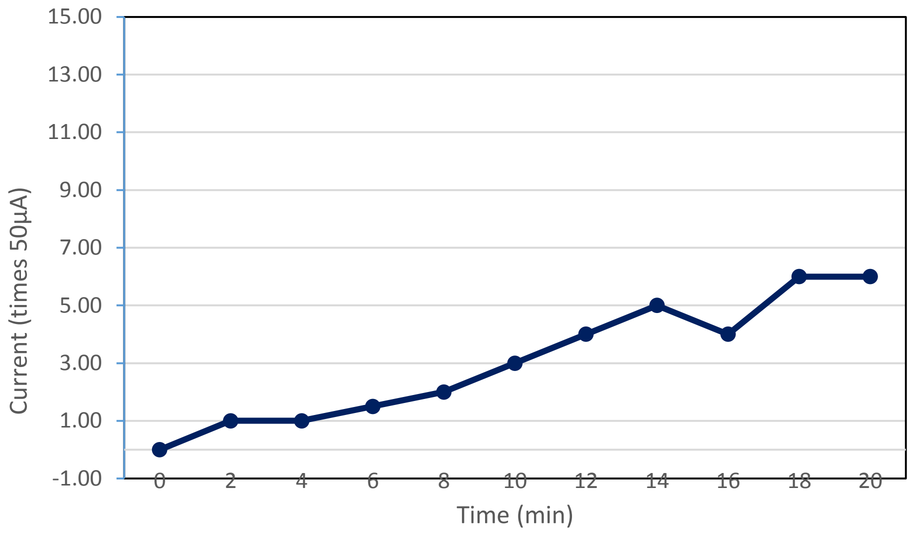

FIGURE 4.18: current reading against time for experiment 5

4.3.6 Experiment 6 (SiC/Nickel electrode in KOH with sunlight illumination)

In experiment 6, silicon carbide (SiC) material is used as semiconductor material while nickel placed at the counter electrode. It is immersed in Potassium hydroxide (KOH) solution 0.1 M. the experiment is conducted with sunlight illumination at room condition for 20 minutes. Table 4.10 shows the experimental data for voltage and current reading against time.

TABLE 4.10: Voltage and Current Reading for Experiment 6

Time (min)	**voltage (V)**	**Current (Times 50µA)**
0	0.1934	10.00
2	0.2065	13.00
4	0.2344	12.00
6	0.2505	13.50
8	0.2659	13.75
10	0.2857	13.75
12	0.3014	14.00
14	0.3031	14.00
16	0.2925	13.75
18	0.2845	13.00
20	0.2785	13.00

Figure 4.19 and 4.20 shows the voltage and current trend respectively throughout the experiment.

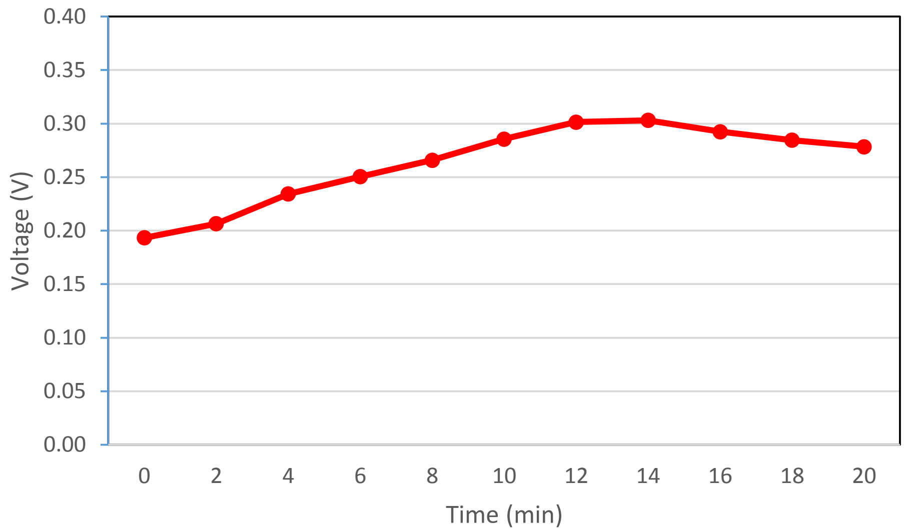

FIGURE 4.19: Voltage reading against time for experiment 6

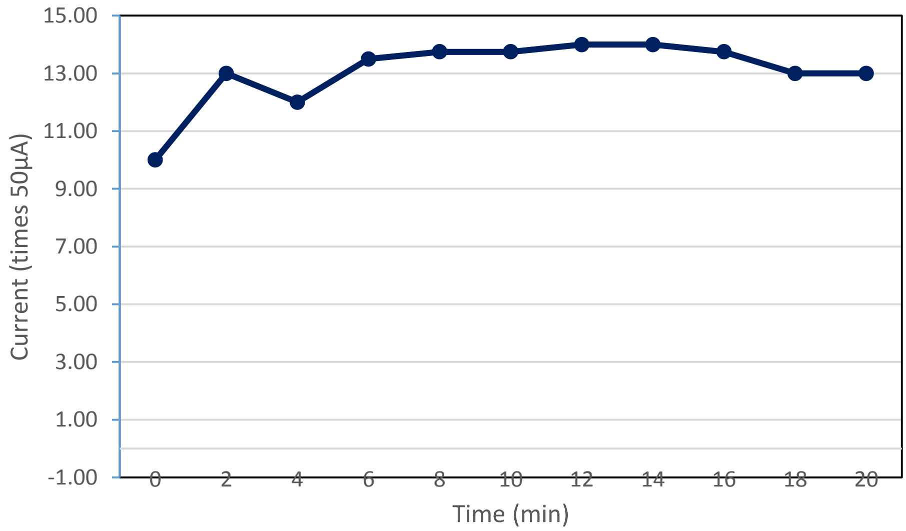

FIGURE 4.20: current reading against time for experiment 6

4.3.7 Experiment 7 (SiC/Nickel electrode in Na_2SO_3 without sunlight illumination)

In experiment 7, silicon carbide (SiC) material is used as semiconductor material while nickel placed at the counter electrode. It is immersed in Sodium Sulfite (Na_2SO_3) solution 0.1 M. the experiment is conducted with sunlight illumination at room condition for 20 minutes. Table 4.11 shows the experimental data for voltage and current reading against time.

TABLE 4.11: Voltage and Current Reading for Experiment 7

Time (min)	voltage (V)	Current (Times 50μA)
0	0.1125	0.50
2	0.1272	0.75
4	0.1189	1.50
6	0.1393	1.50
8	0.1455	1.50
10	0.1473	2.00
12	0.1524	3.00
14	0.1606	2.75
16	0.1635	2.75
18	0.1645	3.00
20	0.1595	3.00

Figure 4.21 and 4.22 shows the voltage and current trend respectively throughout the experiment.

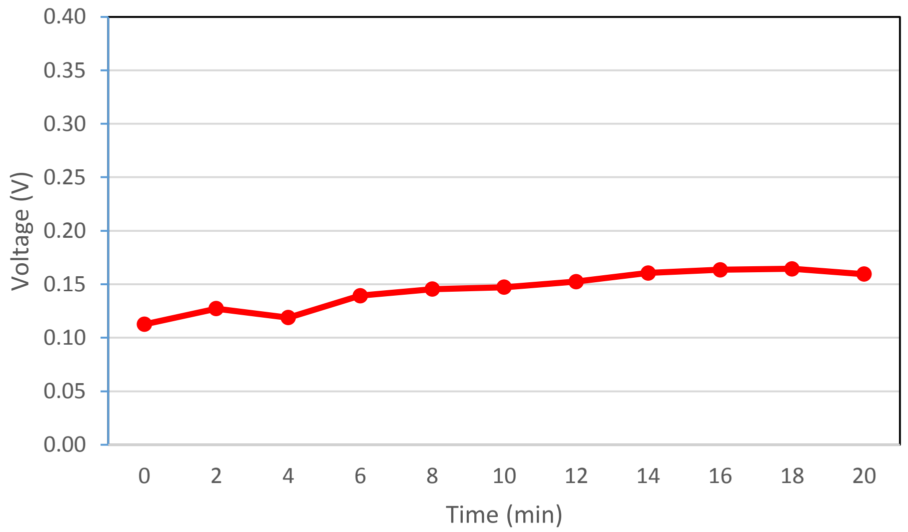

FIGURE 4.21: Voltage reading against time for experiment 7

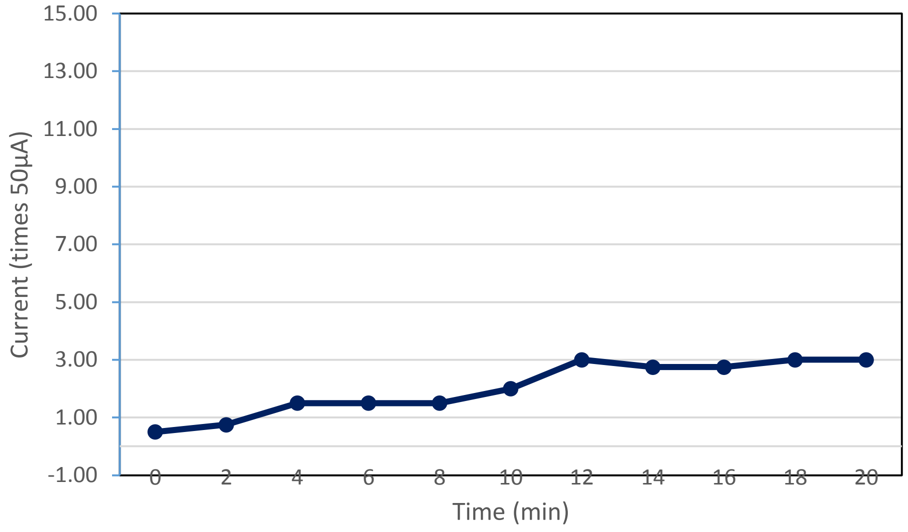

FIGURE 4.22: Current Reading against Time for Experiment 7

4.3.8 Experiment 8 (SiC/Nickel electrode in Na_2SO_3 with sunlight illumination)

In experiment 8, silicon carbide (SiC) material is used as semiconductor material while nickel placed at the counter electrode. It is immersed in Sodium Sulfite (Na_2SO_3) solution 0.1 M. the experiment is conducted with sunlight illumination at room condition for 20 minutes. Table 4.12 shows the experimental data for voltage and current reading against time.

TABLE 4.12: Voltage and Current Reading for Experiment 8

Time (min)	voltage (V)	Current (Times 50µA)
0	0.1240	1.00
2	0.1259	1.50
4	0.1268	1.50
6	0.1727	2.75
8	0.1847	2.50
10	0.2480	5.00
12	0.2523	5.00
14	0.2613	5.50
16	0.2653	5.50
18	0.2615	6.00
20	0.2673	6.00

Figure 4.23 and 4.24 shows the voltage and current trend respectively throughout the experiment.

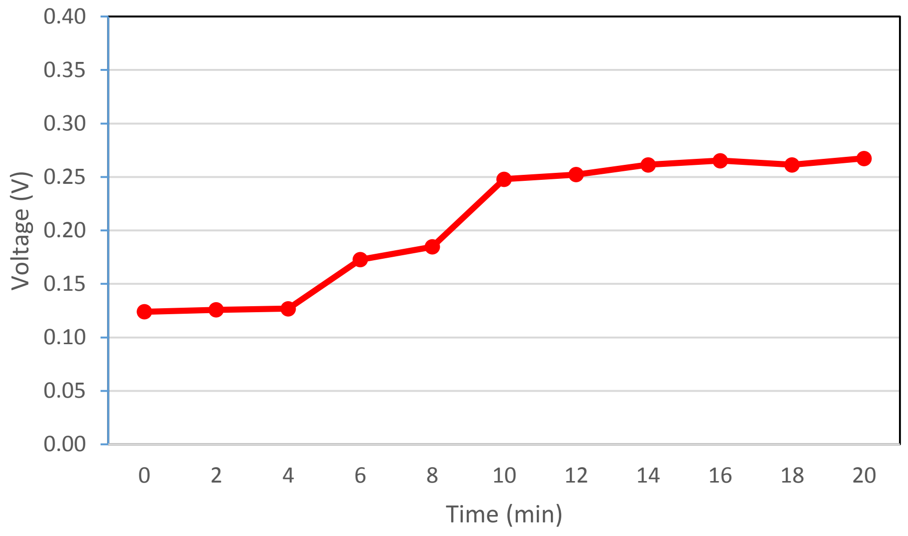

FIGURE 4.23: Voltage reading against time for experiment 8

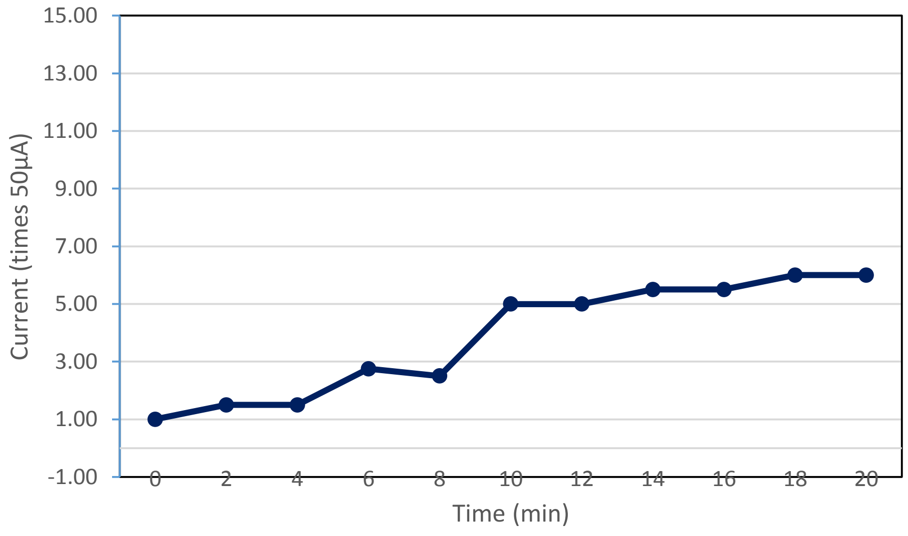

FIGURE 4.24: current reading against time for experiment 8

4.3 Discussion

From the experiment, a significant amount of voltage and current is recorded when silicon carbide semiconductor material is used as electrode. The highest voltage and current value recorded is 0.3031 V and 700 µA respectively. This happen when the experiment conducted using potassium hydroxide (KOH) solution under sunlight illumination by using solar simulator.

The general trend shows the increase of voltage for all experiment, however for current reading only observed when silicon carbide material is used. On the other hand, there are difference in photoelectrochemical cell performance when difference electrolyte is used. Based on result, KOH is observed to be a better electrolyte compared to sodium sulphite (Na_2SO_3).

Through this experiment, the characteristic of n-type or p-type SiC can be identify. Based on the previous work of P.J. Sebastian et al. it is observed that the n-type SiC generate less photocurrent compared to p-type SiC due to the large band gap of of SiC to effect an efficient photogeneration [4]. On the other hand, p-type SiC will have better performance in KOH solution while n-type SiC suit with Na_2SO_3 solution. Thus the experiment result is clearly shows that the SiC extracted from commercial disk sand paper is a p-type SiC semiconductor.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

As conclusion, the used of silicon carbide semiconductor in solar technology offers low production cost and robust technology. In this experiment, silicon carbide material is extracted from a commercial disk type sand paper and undergo chemical cleaning process using toluene, hexane and conventional solvent which is thinner. FESEM analysis shows the component having an average size of 100 to 150 µm and EDX analysis reveal no impurities within the component except formation of oxide on the surface.

In this experiment, the highest voltage recorded is 0.3031 V and current 700 µA. the general trend for both voltage and current is increase over time when silicon carbide material is used under sunlight illumination. The used of KOH electrolyte prove better photoelectrochemical cell performance compared to sodium sulphite (Na_2SO_3). The experiment also indicate the silicon carbide is p-type semiconductor.

The limitation of equipment and chemicals is one of the marvel problems in conducting final year project. The equipment seems to be there in lab but when the students want to use it, it already breakdown. So it is suggested that the equipment should be maintain or repair before the new coming semester as the student need it in completing the project. It will drag time and sometimes give difficulties to student in finishing their project.

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