EFFECTS OF PHOTOANODE THICKNESS ON THE PERFORMANCE OF DSSC SIMULATED USING EQUIVALENT CIRCUIT

By

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DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme in Partial Fulfilment of the Requirements for the Degree
Bachelor of Engineering (Hon.)
Electrical & Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at Universiti Teknologi PETRONAS or other institutions.

Signature : ___________________________

Name : ___________________________

ID No. : ___________________________

Date : ___________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"EFFECTS OF PHOTOANODE THICKNESS ON THE PERFORMANCE OF DSSC SIMULATED USING EQUIVELENT CIRCUIT"** was prepared by **JUFRI HAZLAN BIN JAMALUDIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of (Hons.) Electrical Electronics Engineering at UniversitiTeknologi PETRONAS.

Approved by,

Signature : ___________________________

Supervisor : Dr.Zainal Arif bin Burhanudin

Date : ___________________________

ABSTRACT

In DSSC or any other solar cells, thick absorption layer is preferable as it can maximize the photo-generation of carriers. Unfortunately, the photo-generated carriers need to traverse through the thick layer before it can be collected at the photo-electrodes. This may lead to unwanted phenomena such as loss of photo-generated carriers due to recombination, increase in resistivity, and drop in mobility. For optimization purposes, the balance between thick absorption layer and these unwanted phenomena need to be fully understood and will be investigated. In this work, three DSSCs with 6, 12 and 18 µm absorption layer thickness were fabricated and their current-voltage (IV) characteristics measured. To model the DSSC, a lumped parameter equivalent circuit model consisting of a single exponential-type ideal junction, a constant photo-generated current source, a series parasitic resistance (Rs) and a parallel parasitic conductance (Rsh) was used. The measured and modeled IV characteristics fit reasonably well. From the model, it is shown that both Rs and Rsh will be increased as the thickness of the absorption layer increases. It is also shown that by varying Rs the fill factor will decreased, while the efficiency of the solar cells are decreasing as the material gets thicker.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, I managed to complete this Final Year Project for the Electrical and Electronic Engineering Department, Universiti Teknologi PETRONAS.

A lot has transpired during the study and I am indebt with so many people who has made this course an illuminating and enriching venture. My deepest gratitude goes to my supervisor, Dr Zainal Arif Burhanuddin for guiding me through this course thoroughly and giving me all the support to finish this study. Not to forget my lab colleague, Mr Adel Iskandar Samsudin for helping and giving continuous support towards this course.

Last but not least, to all that help me directly or indirectly helped me out in completing this study.

Thank you.

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1) Background Study

Microelectronics is one of the important fields in Electrical & Electronic, this major cover all about the study and microfabrication of every small electronics design and components. The devices are made from semiconductor. Most of the components that involved in electronic design such as transistor, capacitors, inductors and resistors are made from semiconductor. This field is also important for electrochemical device such as dye sensitized solar cell (DSSC). Therefore, to understand and learning about this major can help the engineers adapt easily during doing this project. There are millions of research papers about automation and control and become more and more development into the future.

As we are in the final year student in Electrical & Electronic department majoring in Automation and Control but performing a project on microelectronics is a challenging moment for us to try to study and understand all the knowledge that related in this field so that we can get an opportunity to become an professional engineer and work into the real industry after graduated.

1.1.1) Dye Sensitized Solar Cells (DSSC)

DSSC is a semiconductor formed between a photo-sensitized anode and electrolyte. These cells were invented by Michael Gratzel and Brian O'Regan and are also known as Gratzel Cells. In Gratzel cells, particles of TiO_2 covered with dye that absorbs at a wide range of wavelengths given by sunlight are placed between the two electrodes in an electrolyte solution containing iodine ions [2]. These cells provide a technical and economically feasible alternative way for conventional p-n junction silicon cells. The use of Titanium Dioxide nanoparticles are inexpensive if compared to the silicon needed for normal cells because they need no expensive manufacturing steps. Besides that, this material TiO2 is already widely used as a paint bas and coffee whiteners. In physics terms, Gratzel cells offer very high efficiencies and the economics are promising because this material is cheap and widely available material [1,2]

1.1.2) Structure

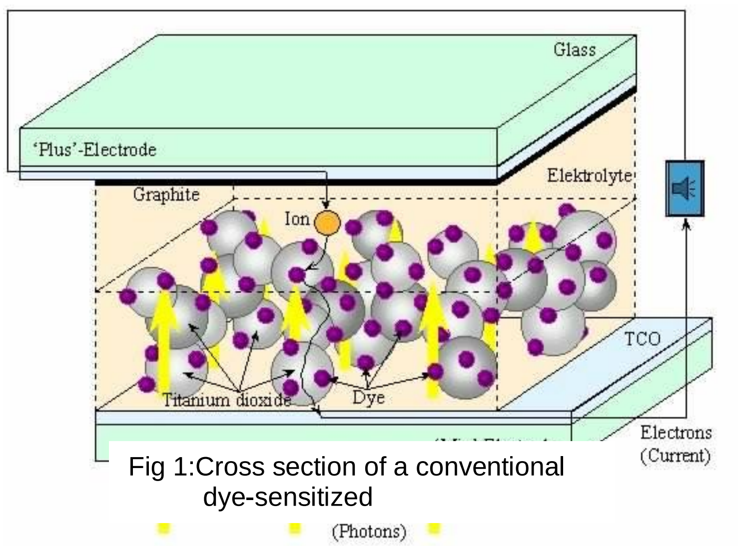
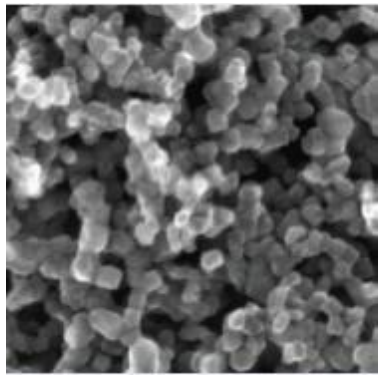


Fig 1:Cross section of a conventional dye-sensitized

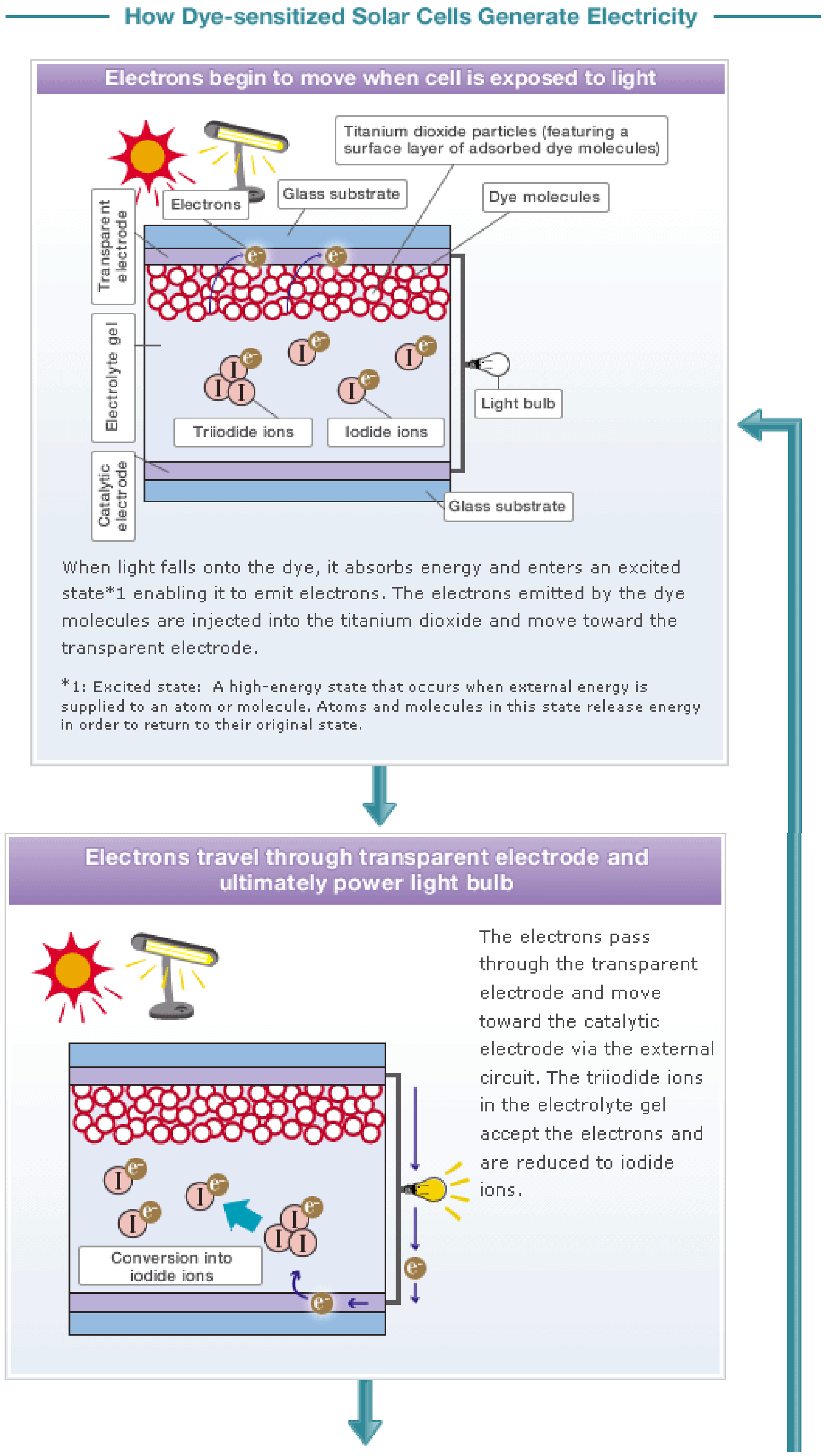
Fig 1: Structure of DSSC

Dye sentisized solar cells have been widely researched and investigated for improvement as a next generation solar cells because of its simple structure as shown above and low manufacturing cost. DSC comprises a nanocrystalline titanium dioxide electrode attached with a dye fabricated on a transparent conducting oxide (TCO), a platinum (Pt) counter electrode, and electrolyte solution with a dissolved iodide ion redox couple between the electrodes. The Titanium Dioxide film provides high internal surface area of dye for high light absorption efficiency. The Swiss Federal Institute of Technology in Lausanne has made and experiment and found that the efficiency of black dye is 10.4% which is higher than usual and it is hardly to be achieved due to insufficient understanding of DSSC.[3]



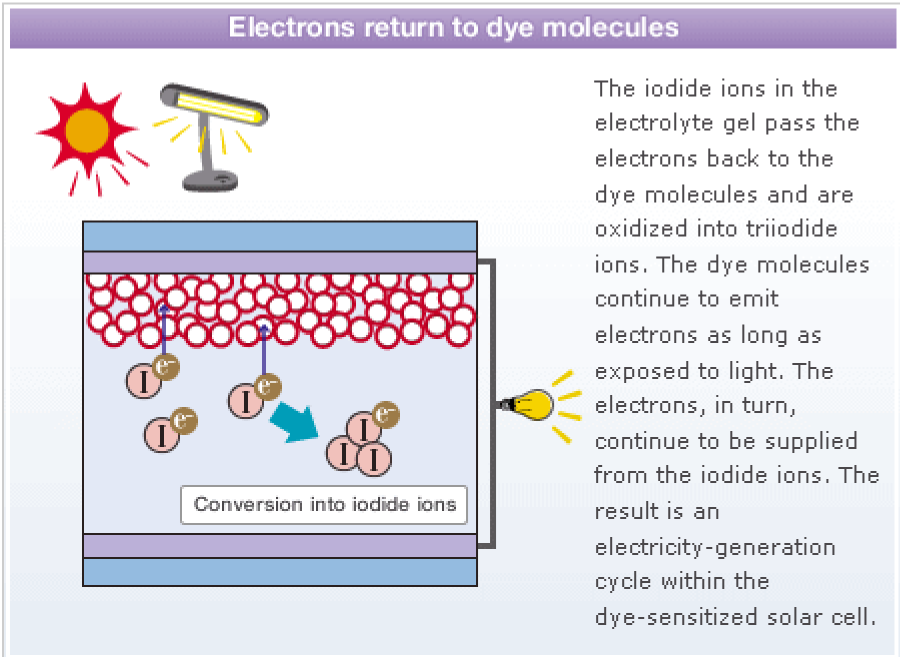
The figure above is the scanned electron microscope image of nanocrystalline TiO_2 film used in a dye-sensitized solar cell. This image was taken from (Michael Gratzel, Dye Sensitized solar cells, J. Photochem. Photobio.2003) [4]

1.1.3) Operation



[5]

[5]


Electrons return to dye molecules
Conversion into iodide ions
I
e⁻
The iodide ions in the electrolyte gel pass the electrons back to the dye molecules and are oxidized into triiodide ions. The dye molecules continue to emit electrons as long as exposed to light. The electrons, in turn, continue to be supplied from the iodide ions. The result is an electricity-generation cycle within the dye-sensitized solar cell.

[5]

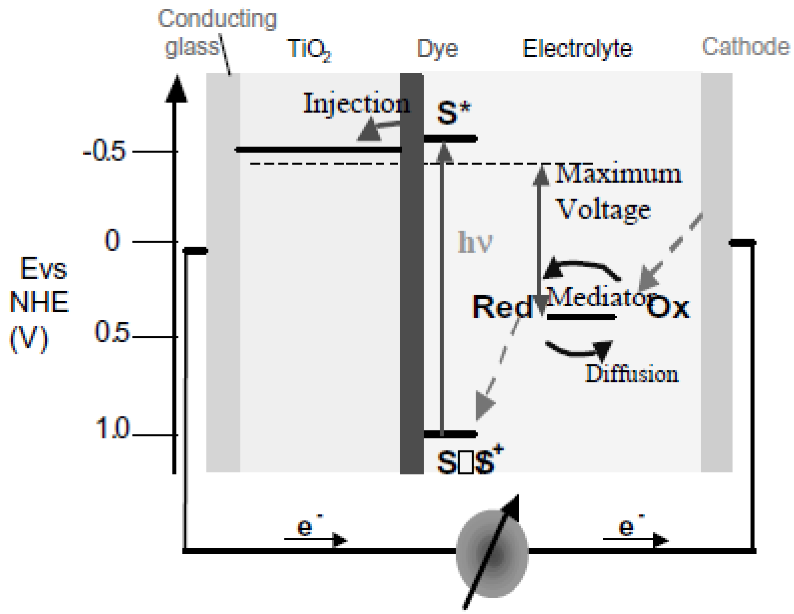


Fig 2: illustration of Dye Operation [6]

The figure above shows the operation of dye solar cell and the energy of electrons flows in the direction of the blue line. Dye will absorbs photon and creates electron/hole from a low energy state. TiO_2 facilitates the charge separation and electron will be injected into the TiO_2. Lastly, an electron will fill the hole in the dye and this completing the circuit. In this experiment, nanoparticles are used because of the enormous surface areas.

1.1.4) Efficiency

The conversion efficiency of solar cell can be expressed as below:

η=FF x I_{sc} x V_{oc}/ P_{in} where

FF- fill factor

I_{sc} - short circuit current

V_{oc} - open circuit current

P_{in} - incident power

The parameters above are the most important element in order to increase the efficiency of solar cell. Generally, there are 3 resistance elements in DSC which is the resistance of TCO, resistance of ionic diffusion and the resistance at the interface between electrode and electrolyte. Previously, the researcher has revealed that the decrease in internal resistance has caused the Fill Factor (FF) to be increased. J_{sc} also has the big consequence on the efficiency of solar cells. The value of J_{sc} obtained from I-V measurement must be consistent with the value estimated from incident photon to current efficiency (IPCE) spectra because J_{sc} can be obtained from the integrating product of flux density and IPCE. [7]

$J_{sc}=\int qF(\lambda)(1-r(\lambda))IPCE(\lambda)d\lambda$ [7]

r(λ) is the incident light loss in light absorption and reflection by conducting glass. It is difficult to obtain accurate IPCE spectra of DSC because IPCE is depending on measurement conditions such as chopping frequency and bias light.

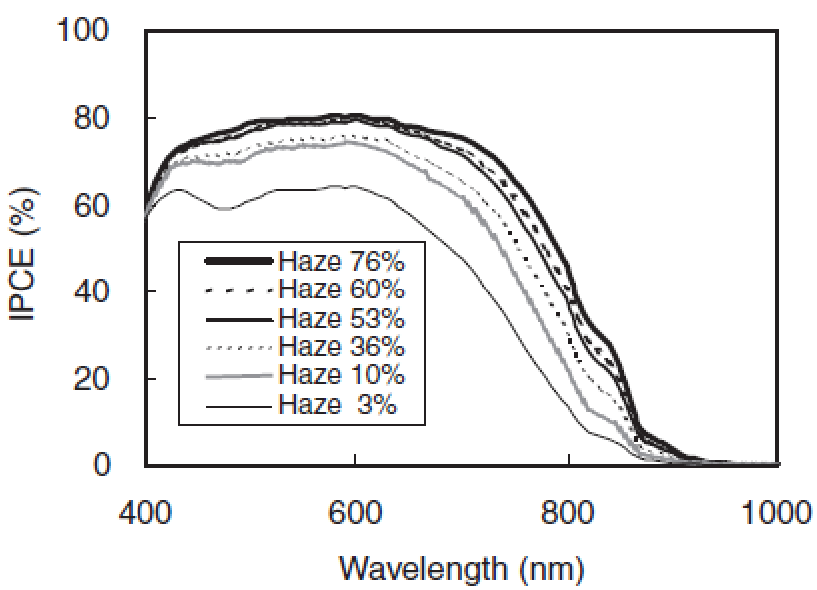


Fig 3: Dependence of IPCE spectra on haze of TiO electrodes. Haze in the figure measured at 800nm [7]

1.1.6) Efficiency for dye-sensitized solar cells (DSSC)

There are few advanced method such as electrical impedance spectroscopy (EIS) which we use to analyze electric mechanisms of cells but it requires much time and the obtained data are complicated to interpret. Few parameters of solar cell performance are calculated from I-V curve using source meter under light irradiation. Parameters such as I_{sc} ,V_{oc}, fill factor (FF) and efficiency (η) are calculated. The I-V curve is used in equivalent circuit analysis by using diode model. In this circuit, there will be series resistance and shunt resistance that can be estimated by fitting the equivalent circuit to I-V curve.

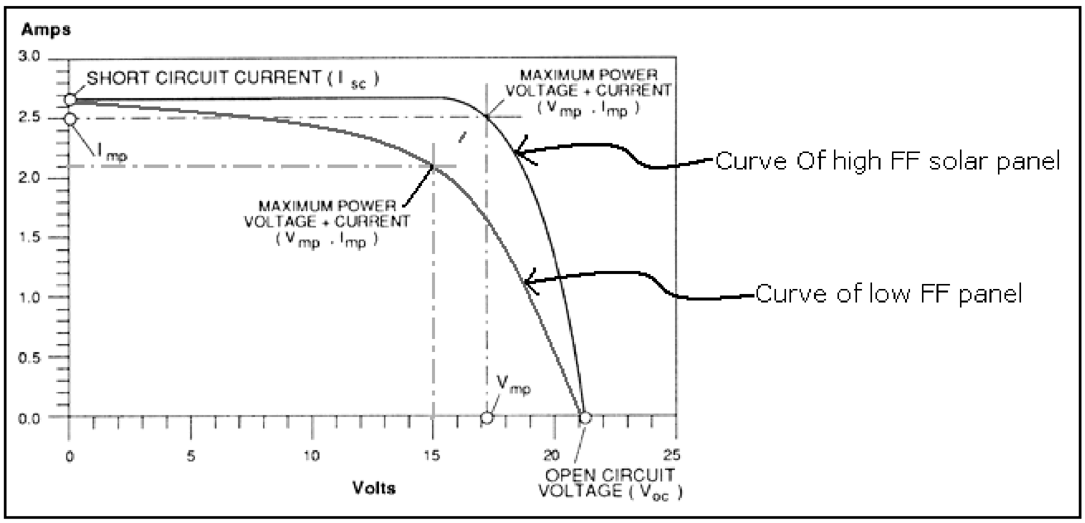


Fig 4: I-V curve for Fill Factor

The diagram above shows the I-V curves of both a high fill factor solar section and a low fill factor section. As can be seen, both curves have the same open circuit voltage and short circuit current, but, the lower fill factor panel actually produces less power at its maximum power point if compared to the higher fill factor panel.

During the manufacture of commercial solar panels, each and every single solar cell will be tested for its fill factor. If its fill factor is low which is below than 0.7, the cells are sold as Grade-B cells, then it can be used for hobbyist use. FF ratio of the solar cells is the actual power output which is (Vpmax x Ipmax) versus its theoritical power output which is (Voc x Isc).

$$FF = \frac{I_{mp}\ X\ V_{mp}}{I_{sc} X\ V_{sc}}$$

$$\eta = \frac{I_{sc}\ X\ V_{oc}\ X\ FF}{P_{sc}}$$

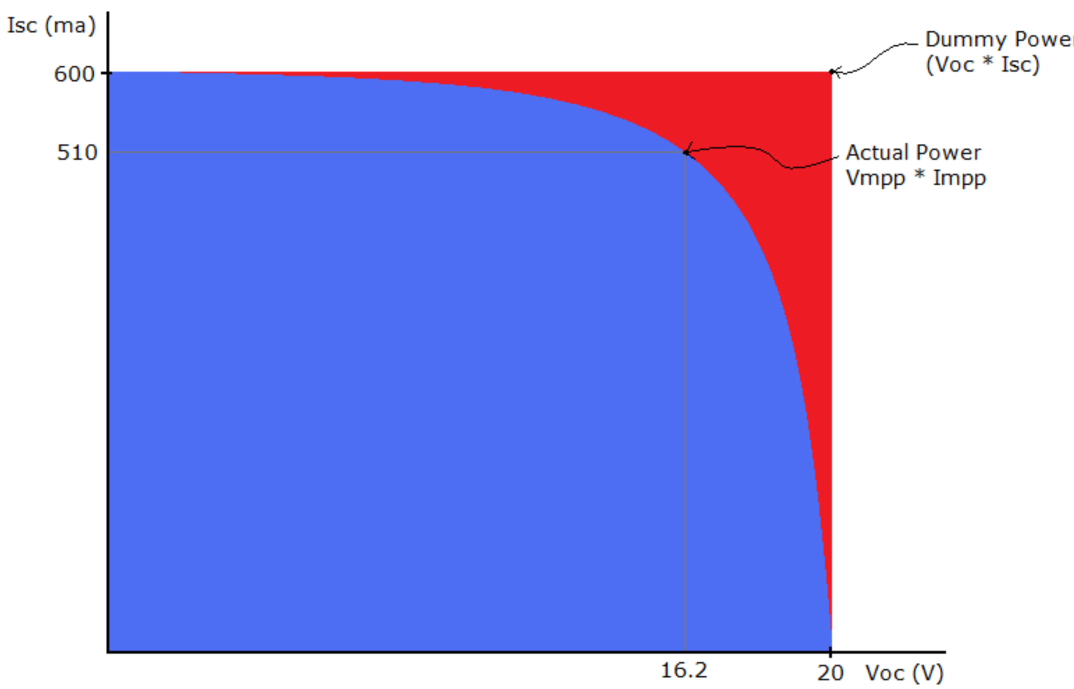


Fig 5: I-V Curve for Dummy and Actual Power

From the I-V curve, we can see that the theoretical power is in the red area, and the actual power is the area in the blue. The fill factor is the ratio of the blue area to the red area which is actual power to the theoretical power. The higher the fill factor of a solar panel, the nearer the blue curve is to the red curve. A solar panel that has higher fill factor has less parasitic losses due to the series and parallel resistances within the cell itself.

1.1.7) Modeling of equivalent circuit for dye sensitized solar cells (DSSC)

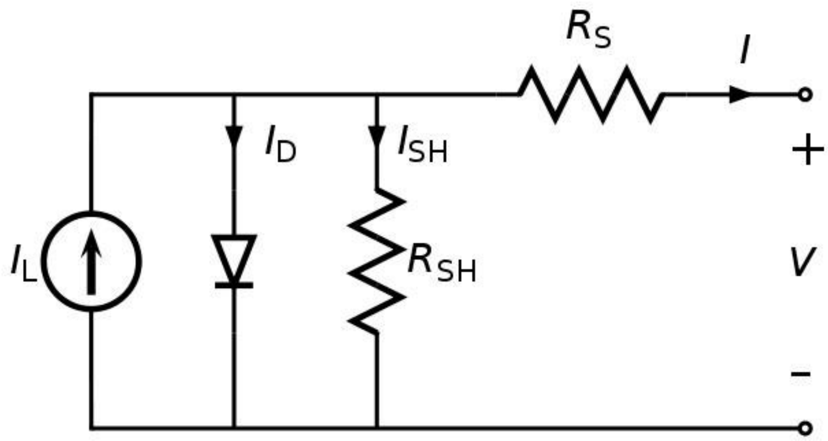


Figure 6: Equivalent Circuit

Figure shown above is the model of equivalent circuit used in this project which consist of current source I_L, diode, 2 resistors (series resistance,Rs and shunt resistance, Rsh) and it works under open circuit condition. The shown figure is the simplest model for solar cells where the current source is in parallel with diode and shunt resistance.

Below are the equations that we used for this equivalent circuit, where diode current I_d and shunt current I_{sh} are written as:

$$I_d = I_o \, [\exp\,(q\,\frac{V+IR_s}{nkT}) - 1]$$

$$I_{sh} = \frac{V+IR_s}{R_{sh}}$$

From the equations above, the circuit operation can be expressed as below

$$I = I_{ph} - I_o \, [\exp\,(q\,\frac{V+IR_s}{nkT}) - 1] - \frac{V+IR_s}{R_{sh}}$$

Where I_{ph} is photo current,

I_o= initial current

R_s= series resistance

R_{sh}= parallel (shunt) resistance

n= diode factor

q= elementary electric charge

k= boltzman constant

T= temperature

Basically, the shunt resistance (Rsh) and series resistance (Rsh) have a striking effect on the performance of DSSC. Rsh is due to the leakage path across the dye interface induced by defects at the surface of the oxide and Rs is the resistance between the cells of Tio2 on the electron transport. For this project, we would like to see the effect of series resistance (Rs) of the equivalent circuit towards the efficiency of the solar cells as the thickness of TiO2 increases for one thickness to another thickness.

1.2) Problem Statement

In this project, we would like to simulate the different thickness of Titania Dioxide (TiO_2) and observe the effects on light absorption towards the dye molecules that attached to the Titania Dioxide. In simulating this project, we will use a software called MATLAB. The function of that software is to provides tools that let the user to do locate, code, and annotate findings in primary data material, to weigh and evaluate their importance, and also to visualize complex relations between them. Lastly plot the desirable graph.

1.3) Objective

The main objective of this project is to perform experiments on the different thickness of Titania Dioxide (TiO_2) using equivalent circuit. Besides that, we will also discuss and carry out some research on the electrochemical device and understand the concept of dye synthesis solar cell. A part of doing research on this topic, we will also gain some experience and knowledge on compiling all the research results by using the right method.

1.4) Feasibility

The feasibility of this project is to complete the project within the scope and time frame, while maintaining substance to this project.

During the first semester (FYP I), the scope and task that will be covered are;

a) Research on the performance of DSSC and it characteristics

b) Propose a suitable method in experimenting this project

c) Analyze several effects on different size of Titania Dioxide

For the following semester (FYP II), the scope and task that will be covered are;

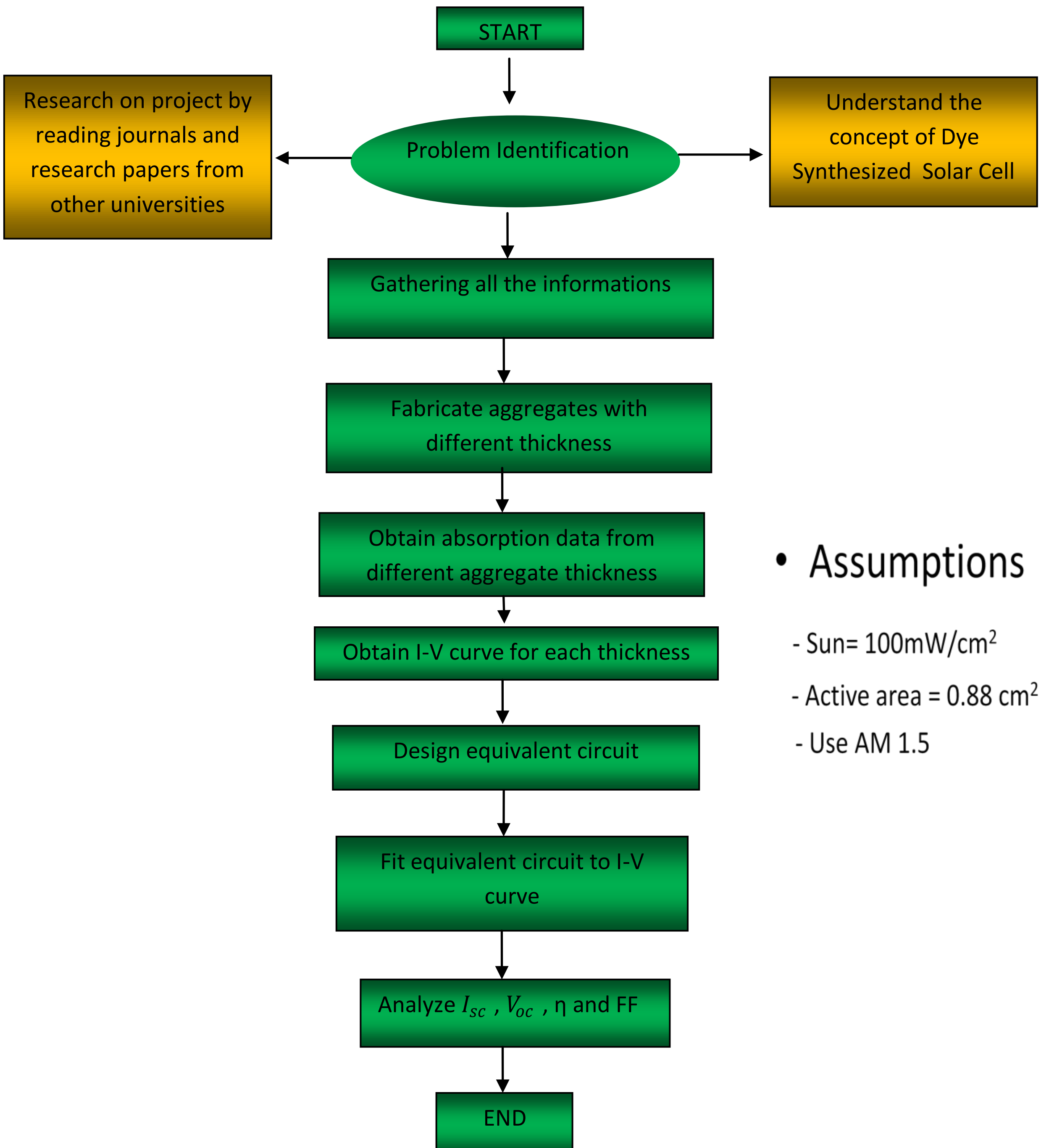
a) Perform in depth experimental analysis to determine the parameter that affects the light absorption

b) Design and propose a better idea in order to increase the light absoption thus increase the efficiency of solar power.

CHAPTER 2

METHODOLOGY

2.1) Project Flow Chart



2.2) Background Works

This project is actually divided into two phase which are semester one and semester two. In the first semester, the student will be focusing more on data gathering, research on the particular project and the paperwork on the literature of the study. For the second semester, the student will be focusing on the practical work such as performing experiment on the scope of the study.

2.3) Expected Result

The expected result throughout this project is to determine the effect of Titanium Dioxide thickness towards the performance of DSSC. As explained before, TiO_2 provides high internal surface to accommodate sufficient amount of dye for light absorption. By performing experiment on different thickness of TiO_2 , we will have different set of series resistance (Rs) value. So, the thicker the TiO_2, the series resistance also will be higher. The increase of Rs value would change the Feed forward (FF) of the solar model. The current theory for this project would be, as the thickness of Titanium Dioxide increased, the efficiency of light absorbing also will be increased as more dye will be attached to the Titanium Dioxide

2.4) Material and Equipments

In this project, the student will use several equipments and material. For the material, the student will need new variation thickness of Titanium Dioxide layers. For the equipments, the student will use a software called MATLAB, which is used to simulate the I-V curve for each thickness of Titanium Dioxide.

2.5) Gantt Chart and Milestone

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■	Mid-Semester Break								
2	Submission of Progress Report									●							
3	Project Work Continues									■	■	■	■	■			
4	Pre-EDX												●				
5	Submision of Draft Report													●			
6	Submission of Dissertation (soft bound)														●		
7	Submission of Technical Paper														●		
8	Oral Presentation															●	
9	Submission of Project Dissertation (Hard Bound)																●

CHAPTER 3

RESULTS AND DISCUSSIONS

3.1 Data Gathering and Analysis

The data used for the simulation of the effect on photoanode size on the performance of Dye Synthesized Solar Cell (DSSC) is the actual historical data taken from my research partner by using the UV-VIS Spectroscopy software. The data consists of the light absorbance data obtained from the input light that went through the different sizes of titanium dioxide using all the measuring equipments.

- **Violet:** 400 - 420 nm
- **Indigo:** 420 - 440 nm
- **Blue:** 440 - 490 nm
- **Green:** 490 - 570 nm
- **Yellow:** 570 - 585 nm
- **Orange:** 585 - 620 nm
- **Red:** 620 - 780 nm

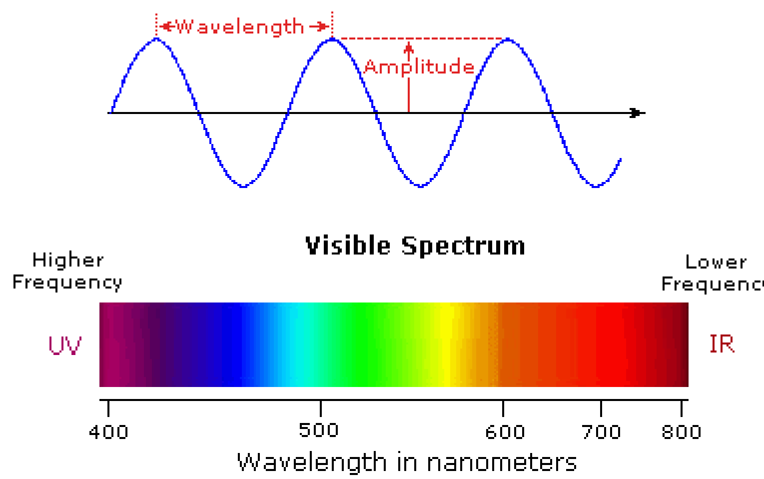


Fig 7: Visible Spectrum For Wavelength

3.1 Fabrication of DSSC with different thickness

1) Groundwork

Prepare the materials that need to be use such as TiO_2 paste, TCO glass and dye

2) Screen printing

For this process there will be 3 different thickness of TiO_2 which are 6 μm, 12 μm, and 18 μm. The TiO_2 paste will be printed on the TCO surface. Basically, each paste will have 6 μm. So, for the 12 μm thickness, we will have to print two layers of TiO_2 paste on the TCO glass and 3 layers for the 18 μm.

Figure 8: Screen Printing Process

3) Drying process

The TCO glass will undergo the drying process using the belt furnace with the temperature of 550 degree Celsius. This process is to dry out the TiO_2 paste layer on the TCO glass.

Figure 9: Belt furnace

4) Dye soaking

Firstly, we have to prepare the dye solution and pour in into a special container, then the TCO glass with TiO_2 paste will be soak into that box. The box need to be closed for 15 hours. To ensure that the soaking process has completed, the color of TiO_2 paste will turn into purple color.

Figure 10: Dye solution

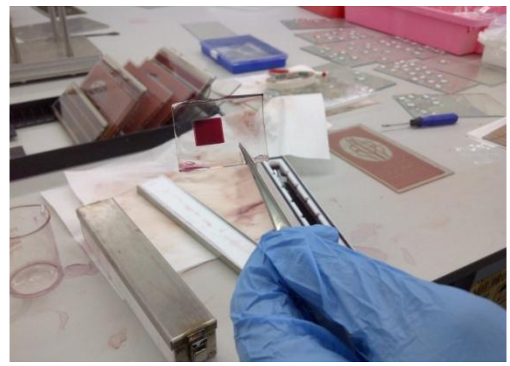


Figure 11: Tio2 with dye

5) Sandwiching

After 15 hours, the TCO glass will undergo for sandwiching process where the soaked TCO glass will sandwiched by another TCO glass that has a small hole in the center. The two glass will be stick together using heat press process. Then, it will go for the cold press process in order to cool down the TCO glass.

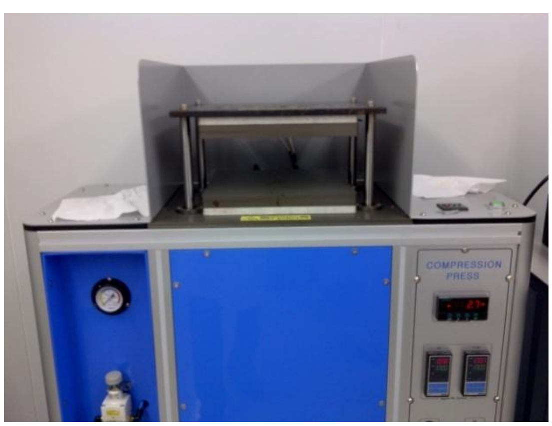


Figure 12: Cold press

Figure 13: Heat press

6) Electrolyte filling process

Electrolyte which is the iodide will be fill through the small hold on the TCO glass using injection method in the pump and vacuum dessicator. Finally, the small hole will be sealed using aluminum foil.

Figure 14: Vacuum Dessicator

3.2 IV curve for different thickness (6 µm, 12 µm, 18 µm)

3.2.1. Experimental result

I-V curve can be obtained using the solar simulator. There are few parameters that we can obtained from this process for the three thickness.

6 µm

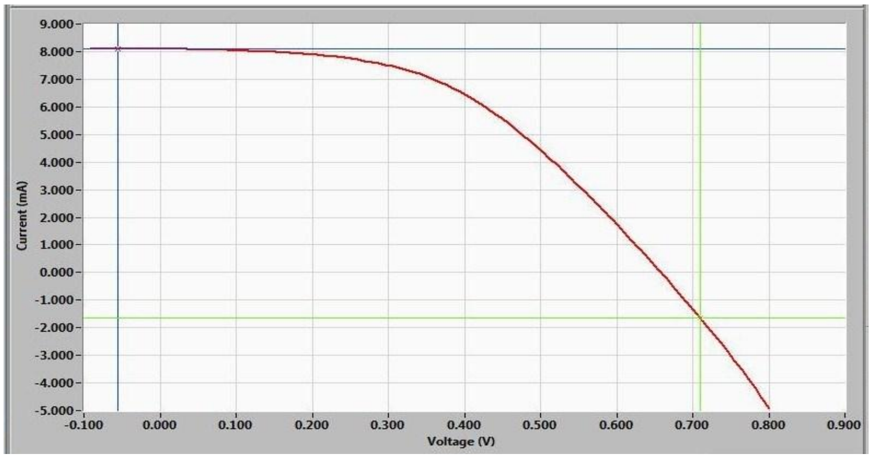


Figure 15: I-V curve for 6 µm

Voc	Vmp	Pmax	Isc	Imp	Jsc	FF	Efficiency
0.660	**0.404**	**2.592**	**8.099**	**6.392**	**8.099**	**0.493**	**2.592**

Table 1 : Performance for 6µm

12µm

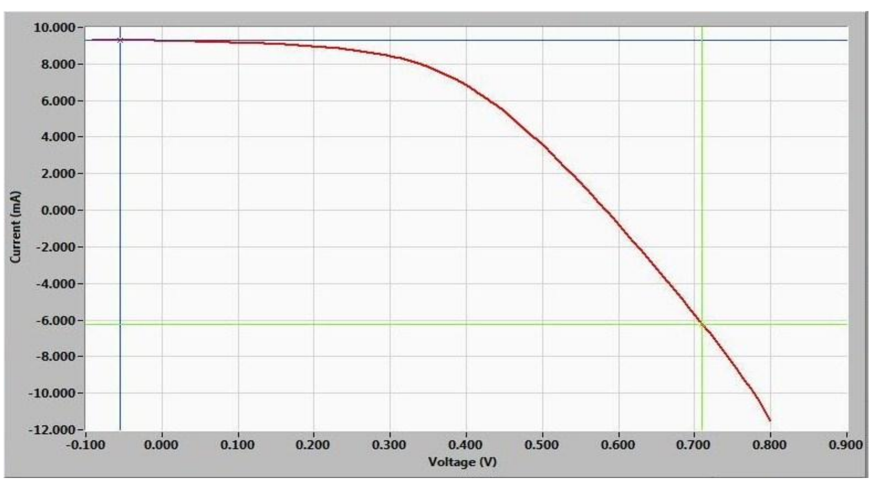


Figure 16: I-V curve for 12 µm

Voc	Vmp	Pmax	Isc	Imp	Jsc	FF	Efficiency
0.583	**0.377**	**2.767**	**9.262**	**7.340**	**9.262**	**0.512**	**2.767**

Table 2 : Performance for 12µm

18µm

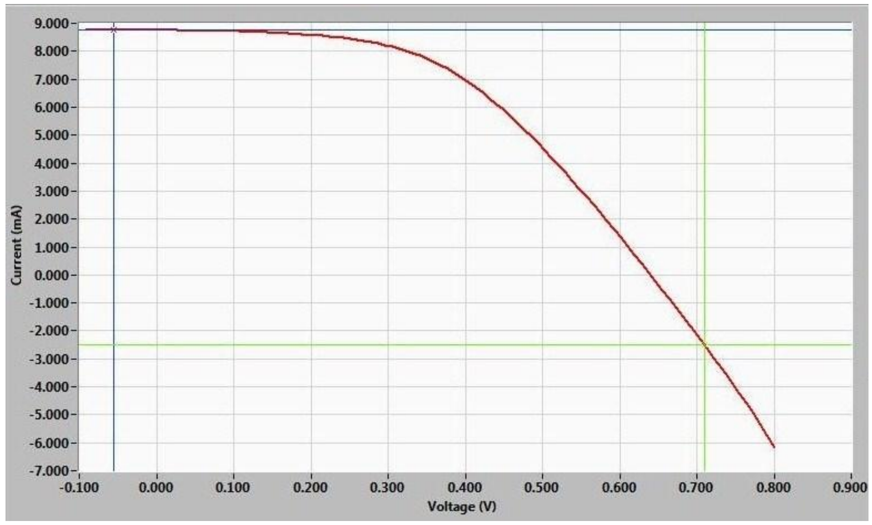


Figure17: I-V curve for 18 µm

Voc	Vmp	Pmax	Isc	Imp	Jsc	FF	Efficiency
0.639	**0.395**	**2.791**	**8.755**	**7.066**	**8.755**	**0.499**	**2.791**

Table 3: Performance for 18µm

3.2.2 Simulation Result

The simulation result can be obtained from the MATLAB model of PV module. This MATLAB model is specially designed to evaluate the Dye Sensitized Solar Cells (DSSC) module during the execution using the equations which will be mentioned in the next section of this report. The MATLAB program has calculated the current I and V using the parameters of the solar module which are Isc and Voc that has been obtained from the experimental result from the previous section. It is suggested that to use numerical method to solve the non-lineal problem. As a result, Newton Raphson method was used in this program to solve the problem in finding the values for the current (I).

In an ideal cell, Rs and Rsh were assumed to be 0. The net current of the cell is the difference between the the normal diode current I_o and the photocurrent I_L. The formula in the next page shows the relationship between these two parameters.

$$I = I_L - I_o(e^{\frac{q(V+IRs)}{nkT}} - 1)$$

The temperature of the cell is also taken into the account of the model. These formulas were used during the simulation in the MATLAB module.

$$K_o = \frac{Isc}{T1}$$

$$I_L = I_L(\mathrm{T1}) + K_o(T - T1)$$

$$I_L(T1) = \mathrm{Isc}\ (T1_{nom})\ \frac{G}{G(nom)}$$

$$I_o(\mathrm{T1}) = \frac{Isc(T1)}{(e^{\frac{qVoc\ (T1)}{nkT\ 1}} - 1)}$$

The series resistance also included in this program which represents the resistance between the Tio2 cells on the electron transportation.

$$\mathrm{Rs} = -\frac{dV}{dI_{Voc}} - \frac{1}{X_v}$$

$$X_v = I_o(\mathrm{T1})\frac{q}{nkT1}\ e^{\frac{qVoc\ (T1)}{nkT\ 1}} - \frac{1}{Xv}$$

In order to simulate the result which consist of the values of current (I), voltage(V) and the I-V curves for the 3 thickness of TiO2. In the next page, there will be the steps done in the MATLAB program in order to obtain the result. This project was set to into a significant condition which is:

a) Sun level = 100mW/cm^2
b) Area (A) = 1cm^2
c) Air mass spectrum (AM) = 1.5
d) Temperature =25 degrees celcius

MATLAB 1

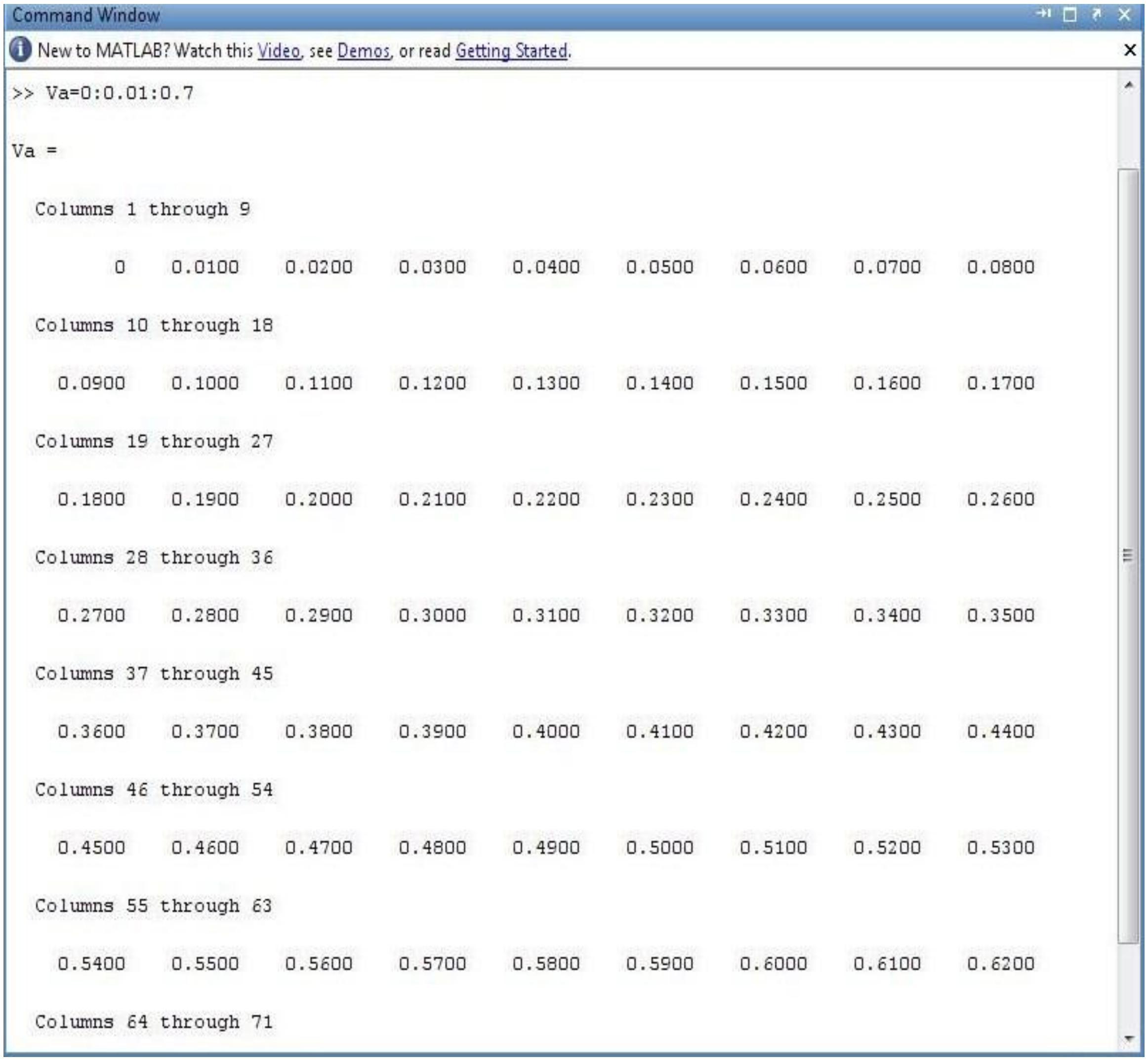
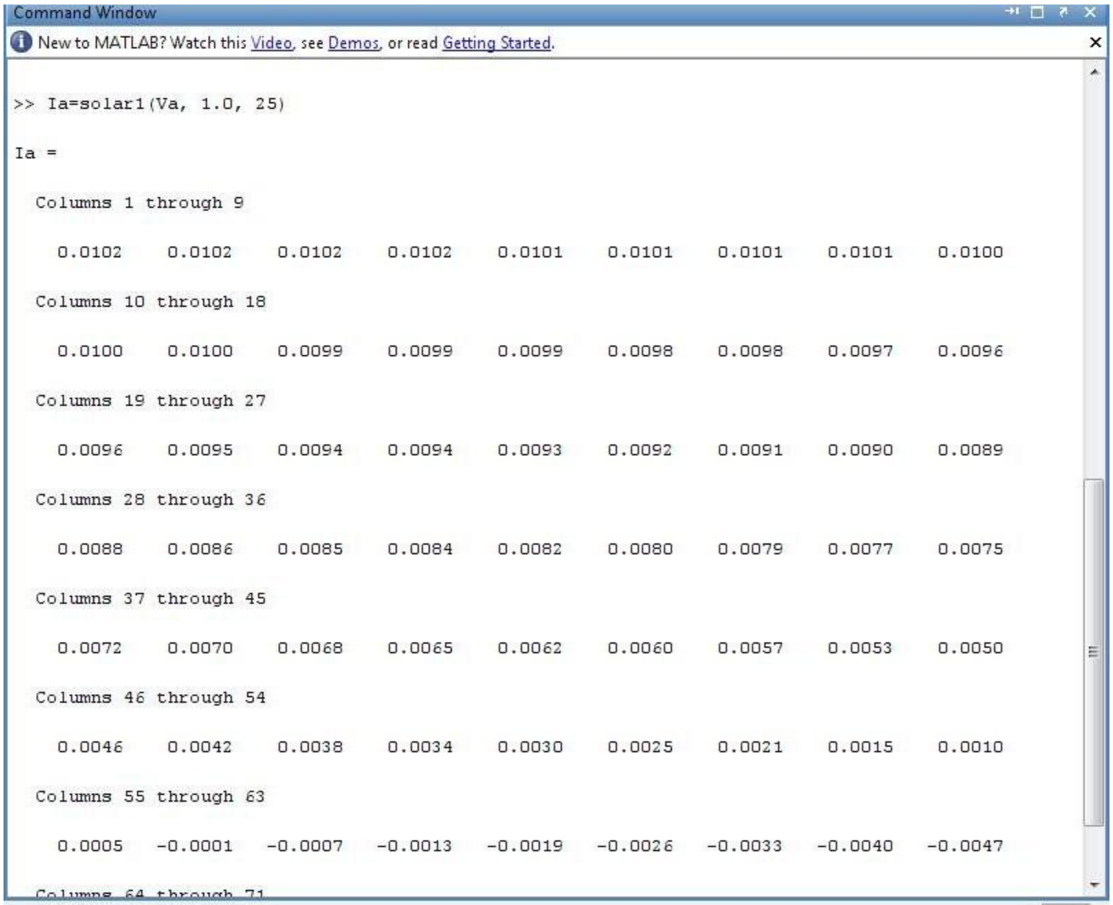


Fig 18: Command for voltage (V)

Figure above shows the command in MATLAB in assigning the value of Voc. In this command window, we assigned the range of the desired voltage that we wish to see the result, so that when the I-V curve is plotted, these values are going to be the X axis of the curve.. For this simulation, the assigned voltage is ranging from 0V- 0.7 V with the step of 0.01V.

MATLAB 2



```
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.

>> Ia=solar1(Va, 1.0, 25)

Ia =

  Columns 1 through 9

    0.0102    0.0102    0.0102    0.0102    0.0101    0.0101    0.0101    0.0101    0.0100

  Columns 10 through 18

    0.0100    0.0100    0.0099    0.0099    0.0099    0.0098    0.0098    0.0097    0.0096

  Columns 19 through 27

    0.0096    0.0095    0.0094    0.0094    0.0093    0.0092    0.0091    0.0090    0.0089

  Columns 28 through 36

    0.0088    0.0086    0.0085    0.0084    0.0082    0.0080    0.0079    0.0077    0.0075

  Columns 37 through 45

    0.0072    0.0070    0.0068    0.0065    0.0062    0.0060    0.0057    0.0053    0.0050

  Columns 46 through 54

    0.0046    0.0042    0.0038    0.0034    0.0030    0.0025    0.0021    0.0015    0.0010

  Columns 55 through 63

    0.0005   -0.0001   -0.0007   -0.0013   -0.0019   -0.0026   -0.0033   -0.0040   -0.0047

  Columns 64 through 71
```

Fig 19: Command for current (I)

In this command window, we have to call the function from the editor (solar1) which consist the parameters of Voltage, Sun level and the Temperature. (V, G, T). From here, we will obtain the Isc value of the I-V curve, which will be Y axis of the I-V curve.

MATLAB 3

Finally we can obtain the I-V curves from the designed program. Below are the curves for each thickness.

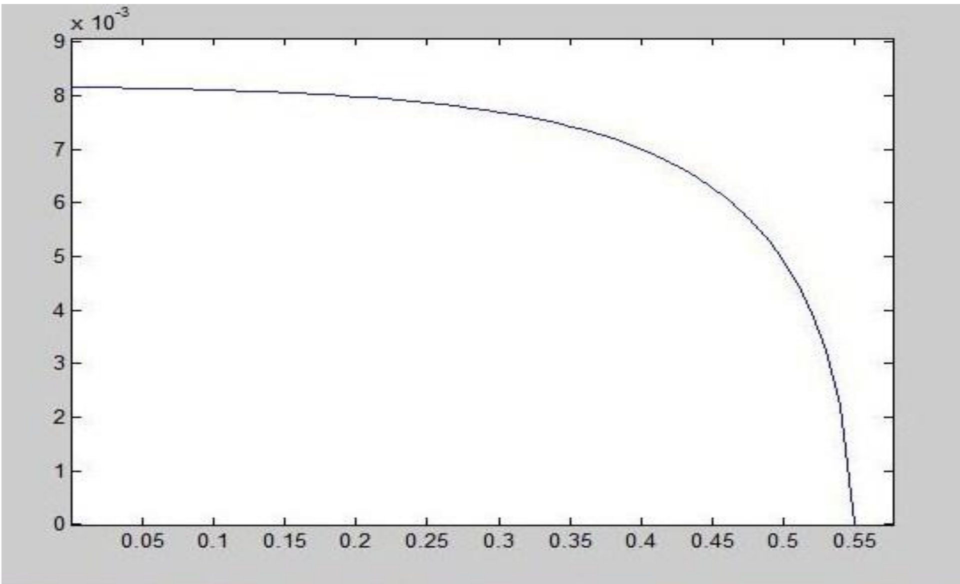


Fig 20: I-V curve for 6μm

Figure 20 shows the I-V curve for 6μm which is plotted in the MATLAB software. As we can see here, the short circuit current, Isc value for this thickness is 8.1mA and the for the open circuit voltage Voc is 0.55V. From this I-V curve, we have obtained few parameters such as fill factor (FF), efficiency, Isc, Voc, Imp (max power) and also Vmp (max power). Below is the table that contained all the parameters which has been obtained from the I-V curve.

Thickness (μm)	FF	Efficiency (η)	Isc (mA)	Voc (V)	Imp (mA)	Vmp (V)
6	0.631	2.80	8.100	0.66	6.5	0.43

Table 4: I-V curve parameters for 6μm

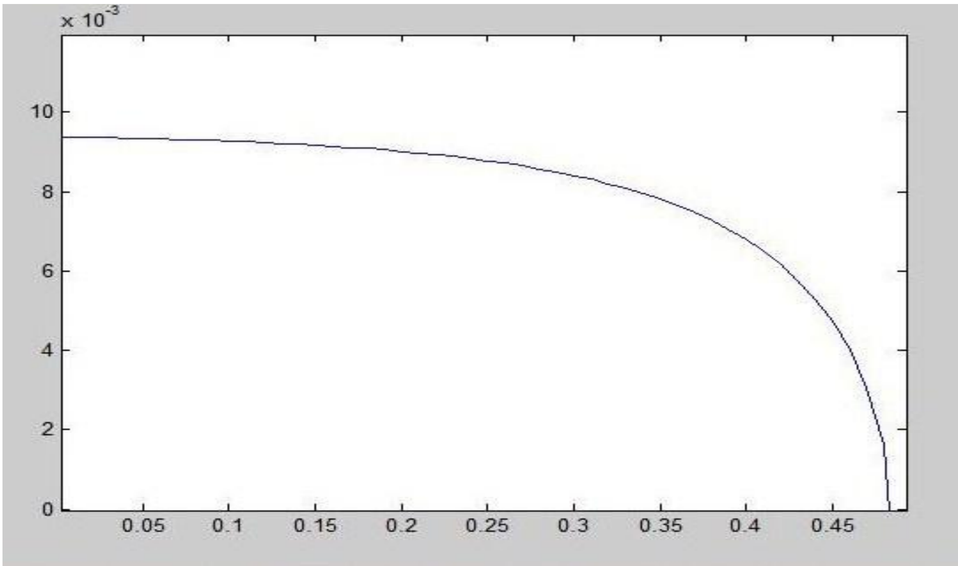


Fig 21: I-V curve for 12µm

Figure 21 shows the I-V curve for 12µm which is plotted in the MATLAB software. As we can see here, the short circuit current, Isc value for this thickness is 9.2mA and the for the open circuit voltage Voc is 0.50V. From this I-V curve, we have obtained few parameters such as fill factor (FF), efficiency, Isc, Voc, Imp (max power) and also Vmp (max power). Below is the table that contained all the parameters which has been obtained from the I-V curve.

Thickness (µm)	FF	Efficiency (η)	Isc (mA)	Voc (V)	Imp (mA)	Vmp (V)
12	0.629	2.81	9.262	0.48	7.00	0.40

Table 5: I-V curve parameters for 12µm

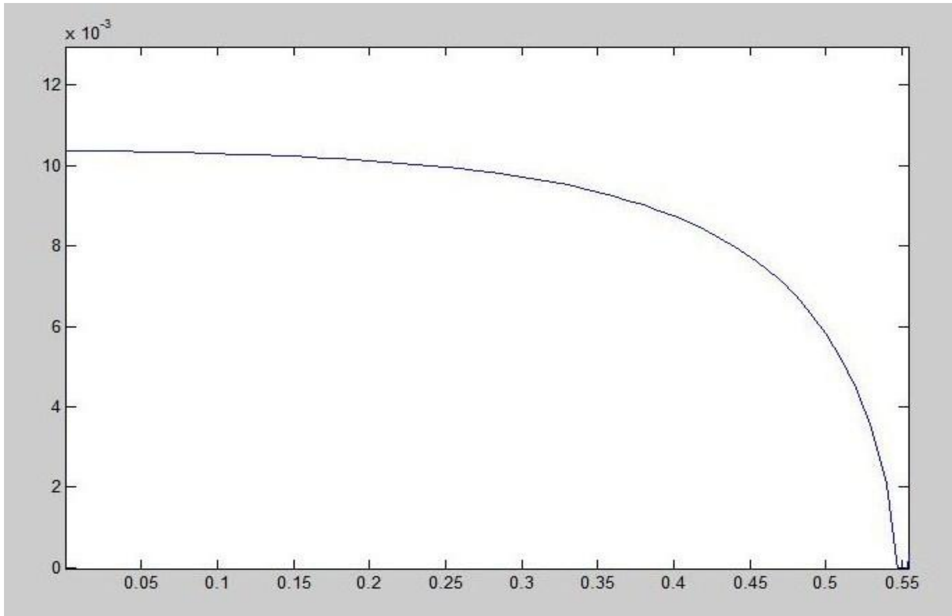


Fig 22: I-V curve for 18µm

Figure 22 shows the I-V curve for 18µm which is plotted in the MATLAB software. As we can see here, the short circuit current, Isc value for this thickness is 10.3mA and the for the open circuit voltage Voc is 0.55V. From this I-V curve, we have obtained few parameters such as fill factor (FF), efficiency, Isc, Voc, Imp (max power) and also Vmp (max power). The value of Isc and Voc for thickness is the highest if compared to the previous two thicknesses which are 6µm and 12µm. Below is the table that contained all the parameters which has been obtained from the I-V curve.

Thickness (µm)	FF	Efficiency (η)	Isc (mA)	Voc (V)	Imp (mA)	Vmp (V)
18	0.621	3.52	10.300	0.55	8.00	0.44

Table 6: I-V curve parameters for 18µm

3.3 Analysis

Thickness (μm)	FF	Efficiency (η)	Isc (mA)	Voc (V)	Imp (mA)	Vmp (V)
18	0.621	3.52	10.300	0.55	8.00	0.44
12	0.629	2.81	9.262	0.48	7.00	0.40
6	0.631	2.80	8.100	0.66	6.5	0.43

Table 7: Summary of I-V curve parameters

Figure 7 shows the summarized of the I-V curve parameters for the 3 thicknesses. As the material goes thicker, the series resistance (Rs) will be increased. This hypothesis was stated in the previous problem statement section. When Rs increases, there is no obvious change in the value of Isc and Vsc on the I-V curves as these values are increasing gradually with the thickness. What we can see here is the value of Fill Factor (FF) is dropping distinctly, but it would not affect the efficiency of the solar cells. The efficiency is increasing as the material gets thicker. In this simulation, the material with 18μm has the highest efficiency. In this simulation, the value of Rs has been set which has the value of 0.7 ohm. The comparison between the experimental result and the simulation result has been made. Both of the results show the efficiency of dye-sensitized solar cells is increasing as the DSSC gets thicker. It is confirmed that series resistance (Rs) does not influence the Isc and Voc but will affect FF instantly. The obtained value of the parameters has been listed in Table 1 in the previous page.

3.4 Comparison

In this section, the author will be discussing on the comparison data between the simulated data and the experimental data. Below are the comparison I-V curves for the 3 thickness which are 6µm, 12µm and 18µm. The simulated curve is in the red line and the experimental is in the green line.

Fig 23: Comparison I-V curve for 6µm

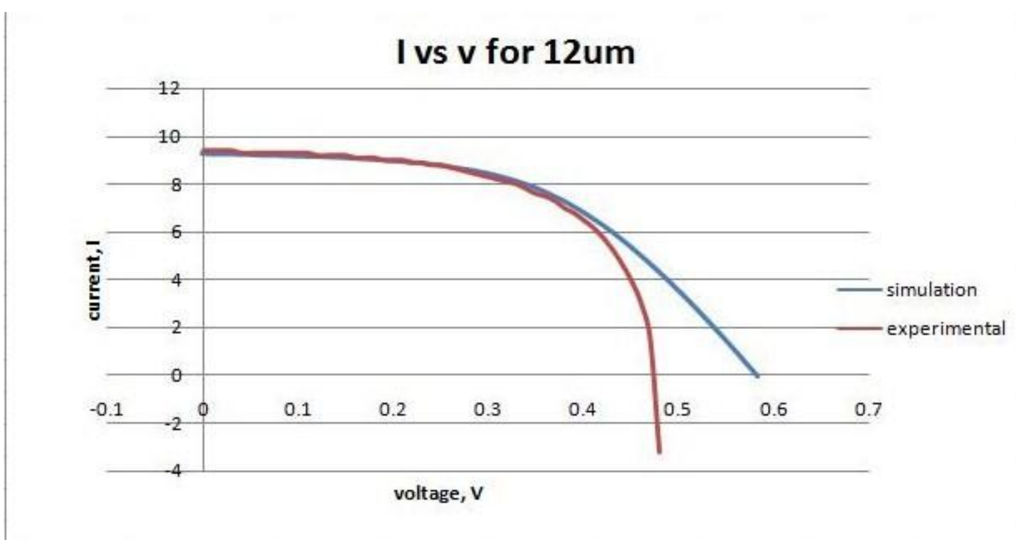


Fig 24: Comparison I-V curve for 12µm

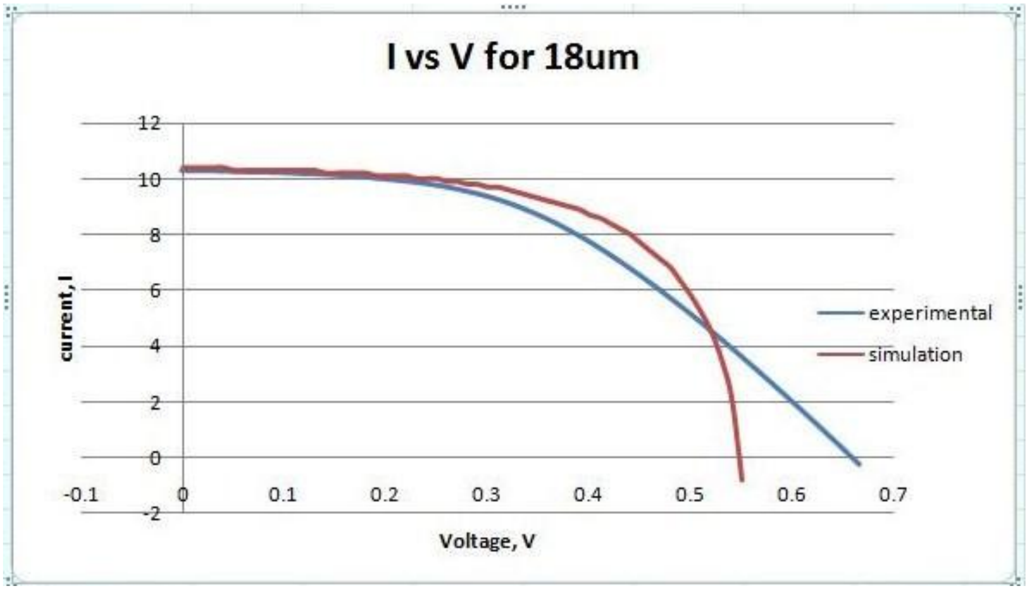


Fig 25: Comparison I-V curve for 18µm

From the I-V curve comparison figures above, it can be seen that the simulated data has the higher fill factor (FF) which is around 0.6 if compared to the experimental data which has the FF value around 0.4. Theoretically, the solar cells are said to be better when the value of FF is approaching the value of 1.00. The value of Voc for both simulated and experimental data is not the same due to the internal error.

CHAPTER 4

CONCLUSION AND RECOMMENDATION

This project is mainly about how to increase the efficiency of light absorption on the dye solar cells by varying the size of Titanium Dioxide. Nevertheless, the pass researchers have not performed investigation on this scope. The student also will find and use suitable method in order to measure the efficiency of dye solar cell based on the Titanium Dioxide characterization. Several assumptions are made to make the experiment and the project become simpler and easy to understand. As the conclusion, we can conclude that the thicker material has the highest efficiency. For the recommendation, I would to recommend the university to go deeper in doing research on this topic. There few things that I have not discovered during performing this project due to the time constrain. Besides that, the students in this university should be exposed to this area because most of them did not know that the university final year student is doing project on this topic.

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APPENDICES

MATLAB CODING

```
function Ia= solar1(Va,Suns,TaC)


n=1.2;
Vg=3.12;
k=1.38e-23;
q=1.60e-19;
Ns=5;
A=1;

T1=273+25;
Voc_T1=0.635/Ns;
Isc_T1=0.007447;



TaK=273+TaC;
K0=Isc_T1/T1;
IL_T1=Isc_T1*Suns;


IL=IL_T1+K0*(TaK-T1);
I0_T1=Isc_T1/(exp(q*Voc_T1/(n*k*T1))-1);
I0=I0_T1*(TaK/T1).^(3/n).*exp(-q*Vg/(n*k).*((1./TaK)-(1/T1)));

Xv=I0_T1*q/(n*k*T1)*exp(q*Voc_T1/(n*k*T1));


dVdI_Voc=(-10.15/Ns)/2;
Rs=-dVdI_Voc- 1/Xv;
Vt_Ta=A*k*TaK/q;
Vc=Va/Ns;
Ia=zeros(size(Vc));
for j=1:5;
   Ia=Ia-(IL-Ia-I0.*(exp((Vc+Ia.*Rs)./Vt_Ta)-1))./(-1-(I0.*(exp((Vc+Ia.*Rs)./Vt_Ta)-
1)).*Rs./Vt_Ta);
end
```