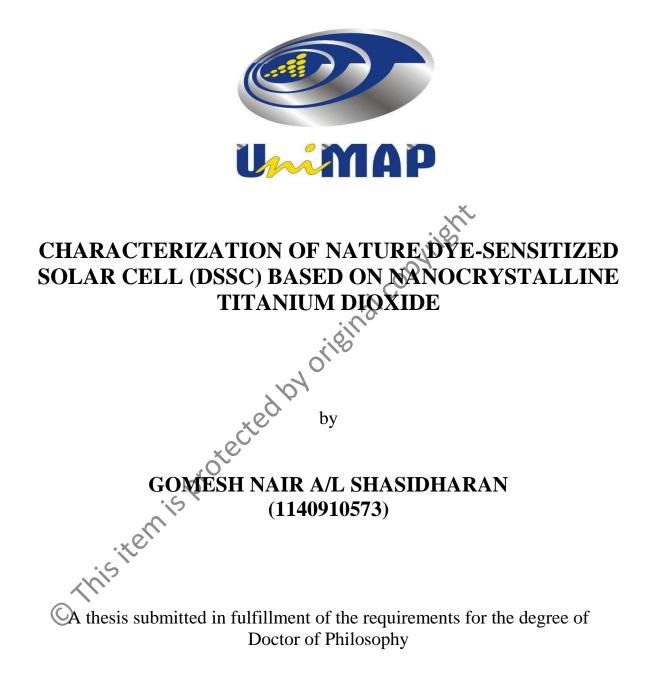
CHARACTERIZATION OF NATURE DYE-SENSITIZED SOLAR CELL (DSSC) BASED ON NANOCRYSTALLINE TITANIUM DIOXIDE

GOMESH NAIR AL SHASIDHARAN

UNIVERSITI MALAYSIA PERLIS 2015



School of Electrical System Engineering UNIVERSITI MALAYSIA PERLIS 2015

UNIVERSITI MALAYSIA PERLIS

		DECLARATION OF THESIS	
Author's full name	:	GOMESH NAIR A/L SHASIDHARAN	
Date of birth	:	06 October 1984	
Title	:	CHARACTERIZATION OF NATURE DYE-SENSITIZED SOLAR CELL (DSSC) BASED ON NANOCRYSTALINE TITANIUM DIOXIDE	
Academic Session	:	2011/2012	
-		s becomes the property of Universiti Malaysia Perlis (UniMAP) f UniMAP. This thesis is classified as :	
CONFIDENT	IAL	(Contains confidential information under the Official Secret Act 1972)	
RESTRICTE	rotect	(Contains restricted information as specified by the organization where research was done)	
	SS	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)	
I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of years, if so requested above).			
		Certified by:	
SIGNAT	URE	SIGNATURE OF SUPERVISOR	
Gomesh Nair	a/l Shasi 6145363	dharan Dr. Muhammad Irwanto	
NEW IC NO.		NAME OF SUPERVISOR	
Dete			
Date :		Date :	

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction.

ACKNOWLEDGMENT

The nature based DSSC project wouldn't be possible without the help and support of many people whom I am in debt for, in which words can't describe the amount of encouragement I've received throughout my PhD work.

I would like to thank God firstly for all the obstacles he made me cross throughout my PhD research; it has made me who I am today. I owe my deepest gratitude to my supervisor Dr. Muhanmad Irwanto and co-supervisors Professor Dr. Uda Bin Hashim and Assoc. Professor. Dr. Johari Adnan, whose ideas and opinions thought me a lot in completing my research. Special thanks to Prof Dr. Uda Bin Hashim and his team of skillful researchers at Institute of Nano Electronics Engineering (INEE) for their help in ensuring that I receive sufficient amount of assistance from the facility. INEE is indeed a world class research facility.

Deepest gratitude also to the members of the Centre of Excellence for Renewable Energy (CERE), Assoc Professor Dr. Mohd Fareq bin Abd Malek, Miss Syafinar Ramli and my good friend Mr. Mohd Irwan bin Yusoff, whom without their assistance, this project wouldn't suffice. Not forgetting my lovely wife Mrs. Thubaasini Prabhakaran whom is the reason for what I am today, your patience and sheer confidence in me made me the person I am now. I extend my gratitude to my beloved family for their support and advise along my research voyage, rest assure you are loved, not forgotten, and shall always be in my heart. I am also very grateful to all personnel in Universiti Malaysia

Perlis and the School of Electrical System Engineering for their supports, awards and grant towards accomplishing this project. Last but not least, I would like to acknowledge the Research Acculturation Collaborative Effort (RACE) 2012 (Grant No: 9017-00006) fund receive from Universiti Putra Malaysia in collaboration with Prof Ir. Dr. Norman Mariun and the Fundamental Research Grant Scheme (FRGS) 2010 (Grant No: 9003-002//) as is the source of funding for this research. A have helped me direct and indirectly I thank you in abundance. No: 9003-00277) as is the source of funding for this research. And finally to those who

TABLE OF CONTENTS

DECLARATION OF THESIS ACKNOWLEDGMENT JE JOT OF ABBREVIATION LIST OF SYMBOLS ABSTRAK ABSTRACTMIS THIS iv xi xiv xxiii xxvi xxvii xxix CHAPTER 1 BACKGROUND 1.1 Introduction 1.2 **Research Problem Statement Research Objective** 1.3 Thesis Organization 1.4

i

ii

1

3

5

6

CHAPTER 2 LITERATURE REVIEW

2.1	Introduction	8
2.2	Reviews on DSSC Technologies	8
	2.2.1 Electrode Thickness	9
	2.2.2 Nature Dye	12
	 2.2.2 Nature Dye 2.2.3 Carbon Counter Electrode (CE) 	16
2.3	TiO ₂ Based Dye sensitized Solar Cell (DSSC)	19
	2.3.1 Titanium Dioxide	19
	2.3.2 DSSC Structure and Its Key Components	22
	2.3.2.1 Fransparent Coating Oxide (TCO)	23
	2.3.2.2 Dye Sensitizer	24
~	2.3.2.2 Dye Sensitizer 2.3.2.3 Electrolytes	26
\bigcirc	2.3.2.4 Counter Electrode (CE)	28
2.4	DSSC Working Principle	31
2.5	Types of Solar Cell	33
	2.5.1 Crystalline Silicon	35
	2.5.2 Thin films	35

	2.5.3 Cadmium Telluride Solar Cell	36
	2.5.4 Copper Indium Gallium Selenide (CIGS)	38
	2.5.5 Multijunction Solar Cell	39
	2.5.6 Quantum Dot Solar Cells (QDSC)	40
	2.5.7 Organic/polymer solar cells	41
2.6	 2.5.0 Quantum Dot Solar Cens (QDSC) 2.5.7 Organic/polymer solar cells Solar Spectrum & Radiation 2.6.1 Solar Insolation 2.6.2 Solar Radiation 	42
	2.6.1 Solar Insolation	43
	2.6.2 Solar Radiation	45
2.7	Solar Cell Characterization Parameters	49
	2.7.1 Efficiency	49
	2.7.2 Efficiency Measurement	50
	2.7.3 Efficiency Limits	51
©	2.7.4 Energy of Photon (E Photon)	54
	2.7.5 Absorption Coefficient (σ cm ⁻¹)	55
	2.7.6 Electrochemical Impedance Spectroscopy (EIS)	57

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Introduction	61
3.2	Experimental Setup	63

	3.2.1.	Equipments and Materials	63
	3.2.2.	Chemical Solutions	65
3.3	DSSC	Fabrication Procedures	68
	3.3.1	Preparation of ITO (Indium Tin Oxide) Conductive Glass for Dye Sensitized Solar Cell (DSSC)	68
	3.3.2	Preparation of TiO ₂ Film	68
	3.3.3	Fabrication of Dye Sensitized Solar Cell Thickness by Using Screen Printing (Dr. Blade Method)	70
	3.3.4	Fabrication of Dye Sensitized Solar Cell Thickness by Spin Coating Method	76
	3.3.5	Fabrication of Dye Sensitized Solar Cell's Counter Electrodes (CE) Thickness by Using Screen Printing and Platinum sputtering Method	79
3.4	Dye E	xtraction from Nature Resource	81
	3.4.1	Extracting Chlorophyll Pigment from Spinach leaves	81
	3.4.2	Extracting Dyes from Fruits and Plant	86
3.5	Physic	cal and Optical Characterization	91
	3.5.1	Electrode Thickness Measurement	91
	3.5.2	Counter Electrode Thickness Measurement	94
	3.5.3	UV-Vis Characterization of Dye Extracts	97

	3.5.4	Electrochemical Impedance Spectra (EIS) Characterization	102
3.6	Photo	electrical Characterization of DSSC samples	112
3.7	Morpl	hological and Microstructure characterization	120
CHA	APTER 4	a RESULTS AND DISCUSSION	
4.1	Introd	uction	123
4.2	TiO ₂ I	Film Thickness Measurement Result	124
4.3		of Anatase based TiO ₂ (A-TiO ₂) Electrode ness on DSSC Electrical Performance	125
		Effect of A-TiO ₂ Thickness on Open Circuit Voltage (Voc)	125
	4.3.2	Effect of A-TiO ₂ Thickness on Short Circuit Current (Isc)	126
	4.3.3	Effect of A-TiO ₂ Thickness on Fill Factor (FF)	128
\odot	4.3.4	Effect of A-TiO ₂ Thickness on Solar cell Efficiency	130
	4.3.5	Overall performance of A-TiO ₂ based on various film Thickness	131
4.4		of Rutile-Anatase mixture based TiO ₂ (RA-TiO ₂) Electrode ness on DSSC Electrical Performance	133
	4.4.1	Effect of RA-TiO ₂ Thickness on Open Circuit Voltage (Voc)	133
	4.4.2	Effect of RA-TiO ₂ Thickness on Short Circuit Current (Isc)	135

	4.4.3 Effect of RA-TiO ₂ Thickness on Fill Factor (FF)	136
	4.4.4 Effect of RA-TiO ₂ Thickness on Solar cell Efficiency	138
	4.4.5 Overall performance and optimum Thickness of TiO ₂ Rutile-Anatase (RA) Electrode in DSSC	139
	4.4.6 Performance Comparison between A and RA TiO ₂ Film Substrate on photoelectrical characteristic	140
4.5	Effect of Various Natures based Dye-sensitizer on 10 and 15 μm RA-TiO ₂ Electrode Thickness for DSSC electrical Performance in terms of UV-Vis Absorption, Absorption Coefficient and Photon Energy	144
	4.5.1 UV-Vis Absorption spectra of Natural Dyes	144
	4.5.2 Effect of 10 and 15 μm AR-TiO ₂ absorbed In Natures Dye Samples	154
4.6	Electrical Characteristic of Nature Dye-sensitizers Absorbed to $10 \ \mu m$ RA TiO ₂ Film at different light intensity	161
4.7	Purification and characterization of anthocyanin extracts from keriang and pucuk merah dyes	171
\$	Investigation on an alternative use of counter electrode (CE) material towards overall DSSC Electrical performance	174
	4.8.1 Comparison of platinum, graphite from pencil lead and graphite from dry cell batteries on DSSC Performance	174
	4.8.2 Battery graphite (BG) Thickness investigation for efficient catalyst	CE 177
4.9	Electrochemical Impedance Spectroscopy (EIS) Analysis of $10 \ \mu m \ TiO_2$ film at varied carbon CE thickness and keriang extract as dye	182

4.10 Energy-Dispersive X-Ray Spectroscopy (EDS) Scanning Electron Microscopy (SEM) Morpho Electrode and Carbon Counter Electrode	
4.11 Economical Feasibility Study on DSSC Fabric Using Nature Based Substance	ation 191
CHAPTER 5 CONCLUSION AND FUTURE REC	COMMENDATIONS
 CHAPTER 5 CONCLUSION AND FUTURE REC 5.1 Introduction 5.2 Conclusion 5.3 Recommendation and Future Work 	PN 198
5.2 Conclusion	199
5.3 Recommendation and Future Work REFERENCES	201
REFERENCES	203
APPENDIX A GRANTS AND PUBLICATIONS	219
APPENDIX B AWARDS	235
PENDIX C PATENT/ PATENT SEARCH (NO	DVELTY SEARCH) 248
APPENDIX D PROGRAM LISTING	249
APPENDIX E SEM MORPHOLOGY	253
APPENDIX F EXPERIMENTAL DATA	259
APPENDIX G LABORATORY EQUIPMENT TE SPECIFICATION	CCHNICAL 276

LIST OF TABLES

NO.		PAGE
2.1	Double Layer Method of TiO ₂ Fabrication of DSSC	9
2.2	Characteristic of TiO ₂ films annealed at different temperatures	11
2.3	Properties of Various Films Printed with Different Paste	12
2.4	Photocurrent, photovoltage, fill factor and photon to electrical conversion efficiency by using natural dyes adapted from several literatures	14
2.5	Physical properties of rutile, and ase and brookite crystalline structures of TiO ₂	22
3.1	List of Solutions	66
3.2	List of fruits and flower used in the extraction method for Nature dye sample	88
4.1	TiO ₂ Electrode Thickness based on Dr. Blade and Spin Coat Method	124
4.2	Data of A-TiO ₂ with various light intensity and thickness on open circuit voltage (Voc)	125
4.3 ¹¹⁻⁷	Data of A -TiO ₂ with various light intensity and thickness on short circuit current (I _{SC})	127
4.4	Data of A -TiO ₂ with various light intensity and thickness on fill factor (FF)	128
4.5	Data of A-TiO ₂ with various light intensity and thickness on solar cell efficiency (η)	130
4.6	Summary of Photoelectrical characteristic of TiO ₂ Film Thickness at STC	131
4.7	Data of RA-TiO ₂ with various light intensity and thickness on open circuit voltage (Voc)	134
4.8	Data of RA-TiO ₂ with various light intensity and thickness on short circuit current (I_{SC})	135

	4.9	Data of RA-TiO ₂ with various light intensity and thickness on Fill Factor (FF)	136
	4.10	Data of RA-TiO ₂ with various light intensity and thickness on solar cell efficiency (η)	138
	4.11	Electrical performance of RA based TiO ₂ Film Thickness	139
	4.12	Summary of A and RA photoelectrical performance	141
	4.13	Test Samples for Electron absorption Spectra adsorbed into RA- TiO ₂	154
	4.14	Overall Parameter of Natural Dyes Solar Absorbance	161
	4.15	Photovoltaic parameter of DSSC sensitized by keriang	162
	4.16	Photovoltaic parameter of DSSC sensitized by pucuk merah	163
	4.17	Photovoltaic parameter of the DSSC sensitized by pitaya dye	166
	4.18	Photovoltaic parameter of DSSC sensitized by spinach leaf extract	168
	4.19	Summary of DSSC Electrical performance based on RA-TiO ₂ Thickness of 10 μ m at 100 mW/cm ²	169
	4.20	Photoelectrochemical parameters of the DSSCs from Sample A- K, B-K, A-PM and B-PM	172
C	4.2115	Photoelectrochemical of DSSC by using various CE material sources	175
C	4.22	Photoelectrochemical characteristic of BG substrate with different carbon thickness at 100 mW/cm^2 light intensity	180
	4.23	Electrochemical impedance spectroscopy (EIS) measurements with different BG-CE thickness	183
	4.24	Nature based DSSC & DSSP Parameters	191
	4.25	Comparison of conventional DSSC (Ru & Pt) with nature based DSSC (Keriang & Carbon)	193
	4.26	Material Requirement and cost for 100,000 m^2 (1.8 MW _p) DSSP	195
	F 1.1	Black Plum with Di-Water UV-Vis Data	261

F 1.2	Black Plum with ethanol UV-Vis Data	262
F 1.3	Blueberry with Di-Water UV-Vis Data	263
F 1.4	Blueberry with Ethanol UV-Vis Data	264
F 1.5	Rose with Di-Water UV-Vis Data	265
F 1.6	Rose with Ethanol UV-Vis Data	266
F 1.7	Dragon Fruit with Di-water UV-Vis Data	267
F 1.8	Dragon Fruit with Di-water UV-Vis Data Dragon Fruit with Ethanol UV-Vis Data	268
F 1.9	Spinach leaf with Di-Water UV-Vis Data	269
F 1.10	Spinach leaf with Ethanol UV-Vis Data	270
F 1.11	Mangosteen with Ethanol UV Vis Data	271
F 1.12	Mangosteen with Di-Water UV-Vis Data	273
F 1.13	Green Apple with Di-Water UV-Vis Data	274
F 1.14	Green Apple with Ethanol UV-Vis Data	275
F 1.15	Spinach Flower with Di-Water UV-Vis Data	276
٠	rent	
This		
\odot		

LIST OF TABLES

NO.		PAGE
2.1	Double Layer Method of TiO ₂ Fabrication of DSSC	9
2.2	Characteristic of TiO ₂ films annealed at different temperatures	11
2.3	Properties of Various Films Printed with Different Paste	12
2.4	Photocurrent, photovoltage, fill factor and photon to electrical conversion efficiency by using natural dyes adapted from several literatures	14
2.5	Physical properties of rutile, and ase and brookite crystalline structures of TiO ₂	22
3.1	List of Solutions	66
3.2	List of fruits and flower used in the extraction method for Nature dye sample	88
4.1	TiO ₂ Electrode Thickness based on Dr. Blade and Spin Coat Method	124
4.2	Data of A-TiO ₂ with various light intensity and thickness on open circuit voltage (Voc)	125
4.3 ¹¹⁻⁷	Data of A -TiO ₂ with various light intensity and thickness on short circuit current (I _{SC})	127
4.4	Data of A -TiO ₂ with various light intensity and thickness on fill factor (FF)	128
4.5	Data of A-TiO ₂ with various light intensity and thickness on solar cell efficiency (η)	130
4.6	Summary of Photoelectrical characteristic of TiO ₂ Film Thickness at STC	131
4.7	Data of RA-TiO ₂ with various light intensity and thickness on open circuit voltage (Voc)	134
4.8	Data of RA-TiO ₂ with various light intensity and thickness on short circuit current (I_{SC})	135

	4.9	Data of RA-TiO ₂ with various light intensity and thickness on Fill Factor (FF)	136
	4.10	Data of RA-TiO ₂ with various light intensity and thickness on solar cell efficiency (η)	138
	4.11	Electrical performance of RA based TiO ₂ Film Thickness	139
	4.12	Summary of A and RA photoelectrical performance	141
	4.13	Test Samples for Electron absorption Spectra adsorbed into RA- TiO ₂	154
	4.14	Overall Parameter of Natural Dyes Solar Absorbance	161
	4.15	Photovoltaic parameter of DSSC sensitized by keriang	162
	4.16	Photovoltaic parameter of DSSC sensitized by pucuk merah	163
	4.17	Photovoltaic parameter of the DSSC sensitized by pitaya dye	166
	4.18	Photovoltaic parameter of DSSC sensitized by spinach leaf extract	168
	4.19	Summary of DSSC Electrical performance based on RA-TiO ₂ Thickness of 10 μ m at 100 mW/cm ²	169
	4.20	Photoelectrochemical parameters of the DSSCs from Sample A- K, B-K, A-PM and B-PM	172
	4.21	Photoelectrochemical of DSSC by using various CE material sources	175
C	4.22	Photoelectrochemical characteristic of BG substrate with different carbon thickness at 100 mW/cm ² light intensity	180
	4.23	Electrochemical impedance spectroscopy (EIS) measurements with different BG-CE thickness	183
	4.24	Nature based DSSC & DSSP Parameters	191
	4.25	Comparison of conventional DSSC (Ru & Pt) with nature based DSSC (Keriang & Carbon)	193
	4.26	Material Requirement and cost for 100,000 m^2 (1.8 MW _p) DSSP	195
	F 1.1	Black Plum with Di-Water UV-Vis Data	261

F 1.2	Black Plum with ethanol UV-Vis Data	262
F 1.3	Blueberry with Di-Water UV-Vis Data	263
F 1.4	Blueberry with Ethanol UV-Vis Data	264
F 1.5	Rose with Di-Water UV-Vis Data	265
F 1.6	Rose with Ethanol UV-Vis Data	266
F 1.7	Dragon Fruit with Di-water UV-Vis Data	267
F 1.8	Dragon Fruit with Di-water UV-Vis Data Dragon Fruit with Ethanol UV-Vis Data	268
F 1.9	Spinach leaf with Di-Water UV-Vis Data	269
F 1.10	Spinach leaf with Ethanol UV-Vis Data	270
F 1.11	Mangosteen with Ethanol UV Vis Data	271
F 1.12	Mangosteen with Di-Water UV-Vis Data	273
F 1.13	Green Apple with Di-Water UV-Vis Data	274
F 1.14	Green Apple with Ethanol UV-Vis Data	275
F 1.15	Spinach Flower with Di-Water UV-Vis Data	276
٠	rent	
This		
\odot		

LIST OF FIGURES

NO.		PAGE
2.1	TiO ₂ crystalline of (a) rutile, (b) anatase and (c) brookite	20
2.2	Crystalline structure of (a) anatase, (b) rutile and (c) brookite	21
2.3	Thermodynamic stability of the rutile, anatase, and brookite crystalline structure: (a) effect of the crystal size: (b) effect of the surface area	21
2.4	Structure of Dye-sensitized solar cells DSSC	23
2.5	Chemical bonding of Ru-dye molecule with TiO ₂ surface	26
2.6	Cross Section of a Zinc-carbon battery	30
2.7	Schematic of DSSC representing the working principle of a DSSC	32
2.8	Mono, Poly, and Thin Film Solar cell	36
2.9	NREL compilation of best research solar cell efficiencies from 1976 to 2010	37
2.10	CdTe based thin Film solar cell construction	38
2.415	CIGS based solar cell construction	39
©2.12	Solar Insolation characteristic on the surface of the earth	44
2.13	Solar Insolation Reduced In Proportion To The Cosine Of The Angle	44
2.14	Solar Radiation Spectrum	46
2.15	Wavelength of the solar radiation	47
2.16	(a) Experimental configuration for testing solar cell and modules, (b) Possible setup for measuring the spectral response	50
2.17	I-V curve of a solar cell showing the open circuit voltage	52
2.18	Curve of a solar cell showing the short circuit current	52
2.19	Graph of I-V and power as function of voltage	54

2.20	Typical (a) nyquist and (b) bode plot which signifies impedance spectrum for a DSSC	58
2.21	(a) Constant phase element (CPE) equivalent circuit; (b) a nyquist plot for a complete DSSC	59
3.1	Overall Project Methodology	62
3.2	Research equipments; (a) Solar simulator (b) Spin Coater (c) Centrifuge (d) UV-Vis Spectroscopy (e) Ultrasonic bath (f) Dielectric Analyzer (g) Elcometer (h) Hot plate (i) I-V Measurement (j) Auto Fine coater (k) SEM tool (l) Thickness Profiler	64
3.3	Equipments and materials	65
3.4	Chemicals used in the fabrication process	67
3.5	(a) Indium Tin Oxide (ITO) glass sheets with a sheet resistance of $8\sim12 \ \Omega/\Box$ and (b) conductive side & resistivity check by multimeter	68
3.6	Addition of Triton X-100 into TiO ₂ powder to form a homogenous paste	69
3.7	TiO ₂ solution inside the ultrasonic cleaner	70
3.8	Measurement Thickness of Scotch Tape Using Digital Calliper	71
3.9 5	Three corners of ITO glass is covered by using scotch tape with the desired thickness	71
©3.10	Desired area of dimension for TiO_2 film at 1 cm ²	72
3.11	(a) TiO_2 on the ITO substrate and (b)Flatten TiO_2 paste on ITO Glass	72
3.12	Homogenous layer of TiO ₂ electrode film	73
3.13	Annealing of TiO ₂ film with hot plate	73
3.14	TiO ₂ film immersed into dye sensitizer	74
3.15	TiO ₂ film after sensitizing process	74
3.16	Pencil lead sketched on the ITO Glass as counter electrode	75
3.17	Drops of liquid electrolyte onto the TiO ₂ film	75

	3.18	The DSSC Samples Assembled For Electrical and Absorption Characterization	76
	3.19	ITO Glass placed on vacuum surface	77
	3.20	TiO ₂ solution on ITO glass on the rotary surface	77
	3.21	Semi-transparent TiO_2 electrode film on the ITO glass	78
	3.22	The linearity graph of thickness of TiO ₂ substrate vs. the rotary speed	78
	3.23	(a) Electronic sputtering of platinum (Pt) to the TCO and (b) Carbon from dry cell batteries mashed and smeared on top of the ITO coated glass to a 1 cm ² dimension	80
	3.24	Spinach leaves sample for chlorophyll pigment extraction	81
	3.25	Erlenmeyer flask used to press the spinach	82
	3.26	Extracted spinach in the proper waste container	82
	3.27	Chlorophyll Pigment Separated	83
	3.28	Remove the solvent using a rotary evaporator into powder form	84
	3.29	(a) Chlorophyll dye samples extracted by (b) Ethanol (c) Spinach Flower (d) Di-water (e) Spinach Leaves	85
	3.30	Preparation of dye from pitaya fruit	87
\bigcirc	3.31	Elcometer 456 coating thickness Gauge	91
	3.32	Elcometer Thickness Calibration (a-b) Click Cal (c-d) Place calibrate sample on metal steel, place the probe on the surface of the sample and calibrate until the exact value shown (g-f) remove sample and place probe on metal steel to see the error reading then press Zero button	92
	3.33	Measurement of TiO ₂ and Carbon film thickness	93
	3.34	Elcometer Interface via Computer Real Time Data Measurement	94
	3.35	Counter Electrode Thickness measurement by using Dektak XT Profiler	95
	3.36	The mapping of surface for thickness measurement by surface profiler	96

3.37	Evolution 201 Double Beam UV-Vis Spectrophotometer (a) Test samples compartment (b) Reference sample compartment	97
3.38	Test Samples of Dye in Cuvette Tube	98
3.39	Refill the cuvette with reference of distilled water/ethanol	98
3.40	Water limit of sample in cuvette	99
3.41	Setting the input data of UV-Vis Spectroscopy	99
3.42	Measuring the reference solution Initializing the Dye details Loading Guide Screen	100
3.43	Initializing the Dye details	101
3.44	Loading Guide Screen	101
3.45	The absorbance value for dye sample	102
3.46	Electrochemical impedance spectroscopy and the WinDETE software	103
3.47	WinDETA v5.66 interface	104
3.48	Start Condition to initialize the parameter	104
3.49	Initializing of parameters	105
3.50	Ditialize the list order	106
3.51	Choosing the range of parameter	106
3.52	Choosing the Frequency as the desired Parameter	107
3.53	Verifying the Range Of Frequency	108
3.54	Online Define Axis	108
3.55	Define Window of Impedance	109
3.56	Starting the Impedance Measurement	109
3.57	Impedance data taken from the samples	110
3.58	Save the Required Parameters	110
3.59	Data Extraction	111
3.60	Multiple Data Extraction	111

3.61	Final Result Of the Bode Plot	112
3.62	Solar Light 1 Sun Simulator	113
3.63	(a) DSSC under Solar Simulator (b)-(c) DSSC with light intensity of 1000 W/m ² (d) AM 1.5 filter and light shutter	114
3.64	Light Source from Halogen Lamp in Dark Room and the Cell Configuration	115
3.65	(a) Graphtec Data Logger and (b) Radiometer for Solar intensity measurement	115
3.66	Keithley Model 2450 Sample Measuring Unit (SMU) and Xenon Lamp Power Supply	116
3.67	KickStart Simulation software interface for I-V curve Measurement of DSSC Samples	116
3.68	Welcome page of KickStart Simulation software Interface	117
3.69	Addition of SMU unit with PC interface	118
3.70	Parameter setup for current measurement based on potential biased	118
3.71	Dark to 1000 W/m ² light intensity result obtained and plotted on Excel sheet	119
3.72	Experimental data saved in excel format	119
3.73	JSM -6010LV Scanning Electron Microscopy (SEM) model	121
3.74	(a) Sample Tray for SEM and (b) Conductive wrap by copper foil for better interaction with the SEM	121
3.75	TiO ₂ sample inside the vacuum compartment for SEM test	122
3.76	Microstructure of TiO ₂ sample scanned by SEM	122
4.1	3D representation of varied TiO_2 anatase film thickness and Light Intensity on V_{OC}	126
4.2	3D representation of varied TiO ₂ anatase Film thickness and Light Intensity on I_{SC}	127
4.3	3D representation of varied TiO_2 anatase Film thickness and Light Intensity on FF	129

4.4	3D representation of varied $\text{Ti}O_2$ anatase Film thickness and Light Intensity on η	129
4.5	Overall Photoelectrical Characteristic of DSSC using anatase based TiO ₂ electrode Film at 100mW/cm ² light intensity	131
4.6	3D representation of varied $\rm TiO_2$ rutile-anatase film thickness and Light Intensity on V_{OC}	134
4.7	3D representation of varied TiO ₂ rutile-anatase film thickness and Light Intensity on I_{SC}	135
4.8	3D representation of varied TiO ₂ rutile-anatase film thickness and Light Intensity on FF	137
4.9	3D representation of varied TiO ₂ rutile-anatase film thickness and Light Intensity on η	137
4.10	Overall Photoelectrical Characteristic of DSSC using TiO_2 rutile-anatase electrode Film	140
4.11	Photovoltaic Measurement of anatase (A-TiO ₂) and rutile- anatase (RA-TiO ₂) based TiO ₂ Film substrate with thickness of 9 μ m, 10 μ m and 15 μ m	141
4.12	Solar Cell Efficiency and Fill factor measurement of anatase (A-TiO ₂) and rutile-anatase (RA-TiO ₂) based TiO ₂ Film substrate with thickness of 9 μ m, 10 μ m and 15 μ m	142
4.13	Absorption spectra of keriang Fruit extract in ethanol and di- Water	145
(4.14	Absorption spectra of pucuk merah extract in ethanol and di- water	145
4.15	Absorption spectra of pitaya extract in ethanol and di-water	146
4.16	Absorption spectra of mangosteen extract in ethanol and di- water solution	147
4.17	Absorption spectra of rose extract in ethanol and di-water solution	148
4.18	Absorption spectra of green apple skin extract in ethanol and di- water	149
4.19	Absorption spectra of spinach flower extract in ethanol and di- water	149