UNIVERSITI PUTRA MALAYSIA

STUDY OF POLY(3,4-ETHYLENEDIOXYTHIOPHENE) BASED COUNTER ELECTRODES FOR EFFICIENT DYE-SENSITIZED SOLAR CELL

MUHAMMAD NORHAFFIS MUSTAFA

FS 2018 20

STUDY OF POLY(3,4-ETHYLENEDIOXYTHIOPHENE) BASED COUNTER ELECTRODES FOR EFFICIENT DYE-SENSITIZED SOLAR CELL

By

MUHAMMAD NORHAFFIS BIN MUSTAFA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the requirement for the Degree of Master of Science

November 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

STUDY OF POLY(3,4-ETHYLENEDIOXYTHIOPHENE BASED COUNTER ELECTRODES FOR EFFICIENT DYE-SENSITIZED SOLAR CELL

By

MUHAMMAD NORHAFFIS BIN MUSTAFA

November 2017

Chairman: Associate Professor Yusran Sulaiman, PhD
Faculty: Science

In this work the enhancement of dye-sensitized solar cell (DSSC) performance was studied by developments of new counter electrode (CE) using a combination of three different materials namely poly(3,4-ethylenedioxythiophene) **(**PEDOT), carbon-based material (CBM; graphene oxide (GO), reduced graphene oxide (rGO), nanocrystalline cellulose (NCC) and multi-walled carbon nanotube (MWCNT)) and titanium dioxide (TiO_2). The counter electrode was prepared by coating indium tin oxide (ITO) glass with TiO_2 followed by deposition of PEDOT incorporated with different CBMs to produce novel CEs with high performance. Among the CEs PEDOT-NCC/TiO_2 exhibited the highest PCE of 2.10 % compared to PEDOT-MWCNT/TiO_2 (1.29 %), PEDOT-rGO/TiO_2 (1.10 %) and PEDOT-GO (1.17 %). PEDOT-NCC/TiO_2 also displayed a lower charge transfer resistance (R_{ct} = 2.4 Ω) and higher cathodic peak current density (I_{cp} = -2.60 mA.cm^{-2}) compared to other CEs due to the synergistic effect of high conductivity of PEDOT, high surface area and high optical transparency of NCC and porous structure of TiO_2 that provide large surface area. The impact of this study in photovoltaic technology is to produce an efficient and low cost CE that capable to substitute a typical CE in DSSC which is platinum that is expensive and rare metal. The future plan can be pursued by producing a flexible CE to increase its application in various fields.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENYELIDIKAN KEATAS POLI(3,4-ETILENADIOKSITIOFENA) SEBAGAI ELEKTROD BERLAWANAN YANG BERKESAN UNTUK PEWARNA SEL SOLAR BERKEPEKAAN

Oleh

MUHAMMAD NORHAFFIS MUSTAFA

November 2017

Pengerusi: Profesor Madya Yusran Sulaiman, PhD
Fakulti: Sains

Dalam penyelidikan ini, peningkatan prestasi pewarna sel solar berkepekaan (DSSC) telah dikaji oleh elektrod berlawanan (CE) baru yang telah dicipta menggunakan gabungan tiga bahan yang berbeza iaitu poli (3,4-etilenadioksitiofena) (PEDOT), bahan berasaskan karbon (CBM; grafin oksida (GO), grafin oksida terturun (rGO), selulosa nanokristal (NCC) dan nanotiub karbon berbilang dinding (MWCNT)) dan titanium dioksida (TiO_2). CE telah disediakan dengan menyaluti kaca indium timah oksida (ITO) dengan TiO_2, diikuti oleh pemendapan PEDOT digabungkan dengan CBM yang berbeza untuk menghasilkan CE novel yang berprestasi tinggi. Di antara CEs, PEDOT-NCC/TiO_2 memaparkan kecekapan penukaran kuasa (PCE) yang paling tinggi iaitu 2.10 % berbanding PEDOT-MWCNT/TiO_2 (1.29 %), PEDOT-rGO/TiO_2 (1.10 %) dan PEDOT-GO (1.17 %). PEDOT-NCC/TiO_2 juga menunjukkan rintangan pemindahan caj yang lebih rendah (R_{CT} = 2.4 Ω) dan ketumpatan arus puncak katod yang lebih tinggi (I_{CP} = -2,60 mA.cm^{-2}) berbanding CE yang lain disebabkan oleh kesan sinergi konduksian PEDOT yang tinggi, luas permukaan dan transparensi optik NCC yang tinggi dan struktur berliang TiO_2 yang memberikan luas permukaan yang luas. Kesan kajian ini dalam teknologi photovoltaik adalah untuk menghasilkan CE yang cekap dan berkos rendah yang mampu menggantikan CE yang biasa digunakan didalam DSSC iaitu platinum yang berkos tinggi dan bahan yang jarang ditemui. Pelan pada masa hadapan boleh dilakukan dengan menghasilkan CE yang fleksibel untuk meningkatkan aplikasi DSSC dalam pelbagai bidang.

ACKNOWLEDGEMENT

"In the name of Allah the most gracious and the most merciful".

Alhamdulillah, thanks to Allah S.W.T for His indulgence and His guidance to complete my master's thesis successfully. Besides, I also would like to thanks Allah S.W.T for my health, ability to think, ability to be grateful and all the grace that had been given to me that made who I am today. Furthermore, I also would like to thanks Allah S.W.T for the knowledge and ability to successfully completed writing this thesis.

First of all, I would like to express my earnest appreciation and thanks to Prof. Madya Dr. Yusran Sulaiman who has supported me throughout my research with excellent guidance, constructive comments and endless supports. His continuous suggestions, efforts, motivation and immense knowledge throughout the experimental and thesis are highly appreciated. I also would like to express countless gratitude to my co-supervisors Prof. Dr. Zulkarnain Zainal and Prof. Madya Dr. Suhaidi Shafie for their support, idea and constructive comments throughout my research.

Secondly, I would like to say thank you to Universiti Putra Malaysia (UPM) and ministry of higher education (MOHE) for their financial support through graduate research fellowship (GRF) and fee aid program (MyMaster). With their help I can smoothly did my research and successfully finish my master programme. Once again, thank you very much.

Never to forget, I would like to take this golden opportunity to express my profound gratitude from the bottom of heart to my mother, Mrs Rahmah Binti Abd Majid for her unconditional love, care, understanding and continuous spiritual support throughout all my studies at Universiti Putra Malaysia. Special appreciation and affection are extended to my late father Mr Mustafa Bin Khamis for his motivation and great advice to me on how to survive in this world. I also remembered the famous quote that my father said to me "It is never too late to learn and life is all about probability, you never know your fate until you try it, so never stop trying". Thanks dad.

My heartfelt gratitude is goes to my friends; Nur Nabilah Binti Samsudin and lab mates; Shalini A/P Kulandaivalu, Nur Hawa Nabilah Binti Azman, Abdul Hadi Bin Ismail, Nurul Ain Binti Talib, Nusiba, Muhammad Amirul Aizat Bin Muhammad Abdah, Nurulkhalilah Binti Tukimin, Radha A/P Ravit, Shariffah Nurjannah Bin Zainal Abidin, Muhammad Khairul Syafiq bin Azmi and Lim Pei Teng. Without their constant assistance, moral support and valuable opinions throughout this journey, the research would not be accomplished.

Last but not least, I also would like to convey my warm appreciation to one and all, who directly or indirectly, have stood beside me and lent their hand in this journey.

"There is nothing I can do to undo what I did. I can only say again how sorry I am to those I let down and then strive to go forward with a greater sense of humility and purpose, and with gratitude to those who stood with me during a very difficult chapter in my life".

-David Petraeus-

I certify that a Thesis Examination Committee has met on 16 November 2017 to conduct the final examination of Muhammad Norhaffis Bin Mustafa on his thesis entitled “Study Of Poly(3,4-Ethylenedioxythiophene Based Counter Electrodes For Efficient Dye-Sensitized Solar Cell” in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Ernee Noryana Binti Muhamad, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Lim Hong Ngee, Janet, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Md. Akhtaruzzaman, PhD
Senior Lecturer
Universiti Kebangsaan Malaysia
Malaysia
(External Examiner)

(NOR AINI AB. SHUKOR, PhD)
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 29 January 2018

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Yusran Sulaiman, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zulkarnain Zainal, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

Suhaidi Shafie, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ______________________

Name and Matric No.: Muhammad Norhaffis Bin Mustafa (GS43711)

Declaration By Members of Supervisor Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:__________________________
Name of
Chairman of
Supervisory
Committee: Yusran Sulaiman

Signature:__________________________
Name of
Member of
Supervisory
Committee: Suhaidi Shafie

Signature:__________________________
Name of
Member of
Supervisory
Committee: Zulkarnain Zainal

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol	Meaning	Usual unit
OCP	Open circuit voltage	V
I_{cp}	Cathodic peak current density	$mA.cm^{-2}$
E_{pp}	Peak to peak separation	V
P_{in}	Power input	$mW.cm^{-2}$
P_{max}	Maximum power	mW
J_{sc}	Short circuit current	mA
V_{oc}	Open circuit voltage	V
R_{ct}	Charge transfer resistance	Ω
R_s	Solution resistance	Ω
CPE	Constant phase element	F
Z'	Real impedance	Ω
Z''	Imaginary impedance	Ω
J_o	Exchange current density	$mW.cm^{-2}$
J_{lim}	Limiting diffusion exchange current density	$mW.cm^{-2}$

LIST OF ABBREVIATIONS

ATR	attenuated total reflection
CA	chronoamperometry
CE	counter electrode
CPs	conducting polymers
CPE	constant phase element
CV	cyclic voltammetry
EDOT	3, 4-ethylenedioxythiophene
EIS	electrochemical impedance spectroscopy
FTIR	fourier transforms infrared spectroscopy
ITO	indium tin oxide coated glass
kHz	kilohertz
LSV	linear sweep voltammetry
mA	milli ampere
mM	millimolar
OCP	open circuit potential
PEDOT	poly(3,4 ethylenedioxythiophene)
PEDOT-GO	poly(3,4 ethylenedioxythiophene)-graphene oxide
PEDOT-rGO	poly(3,4-ethylenedioxythiophene)-reduced graphene oxide
PEDOT-NCC	poly(3,4-ethylenedioxythiophene)-nanocrystalline cellulose
PEDOT-MWCNT	poly(3,4-ethylenedioxythiophene)-multiwalled carbon nanotubes
PEDOT-GO/TiO_2	poly(3,4 ethylenedioxythiophene)-graphene oxide/titanium dioxide
PEDOT-rGO/TiO_2	poly(3,4 ethylenedioxythiophene)-reduced graphene oxide/titanium dioxide
PEDOT-NCC/TiO_2	poly(3,4 ethylenedioxythiophene)-nanocrystalline cellulose/titanium dioxide
PEDOT-MWCNT/TiO_2	poly(3,4 ethylenedioxythiophene)-multiwalled carbon nanotubes/titanium dioxide counter electrode
FESEM	field emission scanning electron microscopy
RE	reference electrode
V	volts
WE	working electrode
PEDOT-GO CE	poly(3,4 ethylenedioxythiophene)-graphene oxide counter electrode
PEDOT CE	poly(3,4 ethylenedioxythiophene) counter electrode
GO CE	graphene oxide counter electrode
Pt CE	platinum counter electrode
DSSCs	dye-sensitized solar cell
R_{ct1}	charge transfer resistance at high frequency
R_s	series resistance
$LiClO_4$	lithium perchlorate
R_{ct2}	charge transfer resistance at low frequency
TTIP	titanium isopropoxide
KCl	potassium chloride
N719	ruthenizer 535-bis TBA
Ag/AgCl	silver/silver chloride

XRD	x-ray diffraction
JCPDS	joint committee on powder diffraction standards
AC	alternating current
A.M.	air mass
I_{cp}	cathodic peak current density
$\boldsymbol{I_3^-}$	tri-iodide ion
$\boldsymbol{I^-}$	iodide ion
I-V curves	current-voltage curves
V_{oc}	open circuit voltage
J_{sc}	short circuit current
P_{max}	maximum power
FF	fill factor
η	overall power conversion effiency
J_{max}	maximum current
J_o	exchange current density
J_{lim}	limiting diffusion exchange current density
ECA	electrocatalytic activity
PCE	power conversion efficiency

CHAPTER 1

INTRODUCTION

1.1 Background study

Nowadays, fossil fuel energy undergoes depletion due to the increasing demand for energy supply. Li *et al.* (2006) reported that the fossil fuels resource reserves throughout the world in 2002 can only last 40 years for oil, 200 years for coal and 60 years for natural gas. Thus, renewable energy is needed to overcome this problem. Solar energy is one of the renewable energies that grab the attention of researchers due to the supply of energy from the sun to the earth is gigantic about 3×10^{24} Joules a year that is 10,000 times more than energy consumption of population around the globe. Thus, global energy demand will be satisfied by covering 0.1% of the earth's surface with minimum power conversion efficiency (PCE) of 10% solar cell (Grätzel, 2001).

Dye-sensitized solar cell (DSSC) is a modern type of solar cell that involves four important components which are photoanodes, counter electrode (CE), electrolyte and dye. A typical DSSC uses titanium dioxide (TiO_2), platinum (Pt), tri-iodide/iodide and ruthenizer 535-bis TBA N719 as a source of photoanodes, CE, electrolyte and dye, respectively. O'Regan and Grätzel (1991) reported that 7.1-7.9 % PCE was achieved in simulated solar light for a low cost and high-efficiency DSSC based on colloidal TiO_2 as photoanode. Even though DSSCs have reached PCE as high as 10 % under AM 1.5 (100 mW/cm^2) (Nazeeruddin *et al.*, 1993), the applications of DSSC are still limited due to the expensive and rare material of Pt as a CE. Thus, this study will focus on producing a synergistic effect by fabricating novel CEs containing conducting polymer, carbon-based material and metal oxide to enhance the PCE of DSSC.

1.2 Problem statements

Pt as a CE in DSSC faced a lot of drawbacks such as rare, required high-temperature treatment, undergo corrosion with the electrolyte and high cost. Thus, a novel approach was made to produce new CEs that have promising properties such as high conductivity, high surface area and high availability that can improve the electrocatalytic activity and PCE of DSSC. This research will focus on producing novel PEDOT-GO/TiO_2 CE for efficient DSSC performance. Besides, various carbon-based materials such as reduced graphene oxide (rGO), nanocrystalline cellulose (NCC) and multiwalled carbon nanotube (MWCNT) will be studied throughout this research to produce novel CEs with enhanced DSSC performance which are PEDOT-rGO/TiO_2, PEDOT-MWCNT/TiO_2 and PEDOT-NCC/TiO_2. PEDOT possesses high conductivity, rGO and MWCNT contribute to the high surface area and high conductivity, NCC provides high surface area and high optical transparency while TiO_2 provides high surface area. Thus, the incorporation of PEDOT and various carbon-based material with and without TiO_2 is believed to produce a synergistic effect that can enhance the PCE of DSSC.

1.3 Objectives of research

The objectives of this research are:

1. To fabricate PEDOT-GO/TiO_2 as a counter electrode for DSSC through chronoamperometry technique.
2. To study the effect of PEDOT incorporated with various carbon-based materials (rGO, NCC and MWCNT) and TiO_2 as counter electrodes on the DSSC performance.
3. To characterize the counter electrode using FTIR, XRD, FESEM, CV, EIS, J-V and Tafel polarization analysis.

REFERENCES

Aasmundtveit, K. E., Samuelsen, E. J., Pettersson, L. a. A., Inganäs, O., Johansson, T. and Feidenhans'l, R. (1999) Structure of thin films of poly(3,4-ethylenedioxythiophene). *Synthetic Metals.* 101**.** 561-564.

Abdiryim, T., Ali, A., Jamal, R., Osman, Y. and Zhang, Y. (2014) A facile solid-state heating method for preparation of poly(3,4-ethelenedioxythiophene)/ZnO nanocomposite and photocatalytic activity. *Nanoscale Research Letters.* 9**.** 89-89.

Ahmad, S., Deepa, M. and Singh, S. (2007) Electrochemical synthesis and surface characterization of poly(3,4-ethylenedioxythiophene) films grown in an ionic liquid. *Langmuir.* 23**.** 11430-11433.

Ahmad, S., Guillen, E., Kavan, L., Gratzel, M. and Nazeeruddin, M. K. (2013) Metal free sensitizer and catalyst for dye sensitized solar cells. *Energy & Environmental Science.* 6**.** 3439-3466.

Arbab, A. A., Sun, K. C., Sahito, I. A., Qadir, M. B. and Jeong, S. H. (2015) Multiwalled carbon nanotube coated polyester fabric as textile based flexible counter electrode for dye sensitized solar cell. *Physical Chemistry Chemical Physics.* 17**.** 12957-12969.

Atieh, M. A., Bakather, O. Y., Al-Tawbini, B., Bukhari, A. A., Abuilaiwi, F. A. and Fettouhi, M. B. (2010) Effect of carboxylic functional group functionalized on carbon nanotubes surface on the removal of lead from water. *Bioinorganic Chemistry and Applications.* 2010**.** 1-9.

Bai, S., Bu, C., Tai, Q., Liang, L., Liu, Y., You, S., Yu, Z., Guo, S. and Zhao, X. (2013) Effects of bis(imidazolium) molten salts with different substituents of imidazolium cations on the performance of efficient dye-sensitized solar cells. *ACS Applied Materials & Interfaces.* 5**.** 3356-3361.

Baughman, R. H., Zakhidov, A. A. and De Heer, W. A. (2002) Carbon nanotubes-The route toward applications. *Science.* 297**.** 787-792.

Bay, L., West, K., Winther-Jensen, B. and Jacobsen, T. (2006) Electrochemical reaction rates in a dye-sensitised solar cell—the iodide/tri-iodide redox system. *Solar Energy Materials and Solar Cells.* 90**.** 341-351.

Bi, D., Yang, L., Boschloo, G., Hagfeldt, A. and Johansson, E. M. J. (2013) Effect of different hole transport materials on recombination in $CH_3NH_3PbI_3$ perovskite-sensitized mesoscopic solar cells. *The Journal of Physical Chemistry Letters.* 4**.** 1532-1536.

Biancardo, M., West, K. and Krebs, F. C. (2007) Quasi-solid-state dye-sensitized solar cells: Pt and PEDOT:PSS counter electrodes applied to gel electrolyte assemblies. *Journal of Photochemistry and Photobiology A: Chemistry.* 187**.** 395-401.

Bu, C., Tai, Q., Liu, Y., Guo, S. and Zhao, X. (2013) A transparent and stable polypyrrole counter electrode for dye-sensitized solar cell. *Journal of Power Sources.* 221**.** 78-83.

Burschka, J., Pellet, N., Moon, S.-J., Humphry-Baker, R., Gao, P., Nazeeruddin, M. K. and Gratzel, M. (2013) Sequential deposition as a route to high-performance perovskite-sensitized solar cells. *Nature.* 499**.** 316-319.

Calandra, P., Calogero, G., Sinopoli, A. and Gucciardi, P. G. (2010) Metal Nanoparticles and Carbon-Based Nanostructures as Advanced Materials for Cathode Application in Dye-Sensitized Solar Cells. *International Journal of Photoenergy.* 2010**.** 15.

Casaluci, S., Gemmi, M., Pellegrini, V., Di Carlo, A. and Bonaccorso, F. (2016) Graphene-based large area dye-sensitized solar cell modules. *Nanoscale.* 8**.** 5368-5378.

Chang, B. Y. S., Huang, N. M., An'amt, M. N., Marlinda, A. R., Norazriena, Y., Muhamad, M. R., Harrison, I., Lim, H. N. and Chia, C. H. (2012) Facile hydrothermal preparation of titanium dioxide decorated reduced graphene oxide nanocomposite. *International Journal of Nanomedicine.* 7**.** 3379-3387.

Chang, L. Y., Li, C. T., Li, Y. Y., Lee, C. P., Yeh, M. H., Ho, K. C. and Lin, J. J. (2015) Morphological influence of polypyrrole nanoparticles on the performance of dye-sensitized solar cells. *Electrochimica Acta.* 155**.** 263-271.

Chen, L., Guo, C. X., Zhang, Q., Lei, Y., Xie, J., Ee, S., Guai, G., Song, Q. and Li, C. M. (2013) Graphene quantum-dot-doped polypyrrole counter electrode for high-performance dye-sensitized solar cells. *ACS Applied Materials & Interfaces.* 5**.** 2047-2052.

Chen, L., Tan, W., Zhang, J., Zhou, X., Zhang, X. and Lin, Y. (2010) Fabrication of high performance Pt counter electrodes on conductive plastic substrate for flexible dye-sensitized solar cells. *Electrochimica Acta.* 55**.** 3721-3726.

Chen, M. and Shao, L.-L. (2016) Review on the recent progress of carbon counter electrodes for dye-sensitized solar cells. *Chemical Engineering Journal.* 304**.** 629-645.

Chen, T., Xia, Y., Jia, Z., Liu, Z. and Zhang, H. (2014) Synthesis, Characterization, and Tribological Behavior of Oleic Acid Capped Graphene Oxide. *Journal of Nanomaterials.* 2014**.** 8.

Cheng, H.-M., Chiu, W.-H., Lee, C.-H., Tsai, S.-Y. and Hsieh, W.-F. (2008) Formation of branched ZnO nanowires from solvothermal method and dye-sensitized solar cells applications. *The Journal of Physical Chemistry C.* 112**.** 16359-16364.

Chiu, W.-H., Lee, C.-H., Cheng, H.-M., Lin, H.-F., Liao, S.-C., Wu, J.-M. and Hsieh, W.-F. (2009) Efficient electron transport in tetrapod-like ZnO metal-free dye-sensitized solar cells. *Energy & Environmental Science.* 2**.** 694-698.

Chou, C.-S., Hsiung, C.-M., Wang, C.-P., Yang, R.-Y. and Guo, M.-G. (2010) Preparation of a Counter Electrode with P-Type NiO and Its Applications in Dye-Sensitized Solar Cell. *International Journal of Photoenergy.* 2010**.** 9.

Chu, J. B., Huang, S. M., Zhang, D. W., Bian, Z. Q., Li, X. D., Sun, Z. and Yin, X. J. (2009) Nanostructured ZnO thin films by chemical bath deposition in basic aqueous ammonia solutions for photovoltaic applications. *Applied Physics A.* 95**.** 849-855.

Danieli, T., Colleran, J. and Mandler, D. (2011) Deposition of Au and Ag nanoparticles on PEDOT. *Physical Chemistry Chemical Physics.* 13**.** 20345-20353.

Demir, E., Sen, B. and Sen, F. (2017) Highly efficient Pt nanoparticles and f-MWCNT nanocomposites based counter electrodes for dye-sensitized solar cells. *Nano-Structures & Nano-Objects.* 11**.** 39-45.

Du, C. and Pan, N. (2006) Supercapacitors using carbon nanotubes films by electrophoretic deposition. *Journal of Power Sources.* 160**.** 1487-1494.

Duan, Y., Fu, N., Liu, Q., Fang, Y., Zhou, X., Zhang, J. and Lin, Y. (2012) Sn-doped TiO_2 photoanode for dye-sensitized solar cells. *The Journal of Physical Chemistry C.* 116**.** 8888-8893.

Fan, J.-S. and Li, Y.-H. (2012) Maximizing the yield of nanocrystalline cellulose from cotton pulp fiber. *Carbohydrate Polymers.* 88**.** 1184-1188.

Gemeiner, P., Peřinka, N., Švorc, Ľ., Hatala, M., Gál, L., Belovičová, M., Syrový, T. and Mikula, M. (2017) Pt–free counter electrodes based on modified screen–

printed PEDOT:PSS catalytic layers for dye–sensitized solar cells. *Materials Science in Semiconductor Processing.* 66**.** 162-169.
Ghani, S., Sharif, R., Bashir, S., Zaidi, A. A., Rafique, M. S., Ashraf, A., Shahzadi, S., Rafique, S. and Kamboh, A. H. (2015) Polypyrrole thin films decorated with copper nanostructures as counter electrode for dye-sensitized solar cells. *Journal of Power Sources.* 282**.** 416-420.
Gong, F., Wang, H., Xu, X., Zhou, G. and Wang, Z. S. (2012a) In situ growth of Co 0.85Se and Ni 0.85Se on conductive substrates as high-performance counter electrodes for dye-sensitized solar cells. *Journal of the American Chemical Society.* 134**.** 10953-10958.
Gong, J., Liang, J. and Sumathy, K. (2012b) Review on dye-sensitized solar cells (DSSCs): Fundamental concepts and novel materials. *Renewable and Sustainable Energy Reviews.* 16**.** 5848-5860.
Grätzel, C. and Zakeeruddin, S. M. (2013) Recent trends in mesoscopic solar cells based on molecular and nanopigment light harvesters. *Materials Today.* 16**.** 11-18.
Grätzel, M. (2001) Photoelectrochemical cells. *Nature.* 414**.** 338-344.
Grätzel, M. (2005) Solar energy conversion by dye-sensitized photovoltaic cells. *Inorganic chemistry.* 44**.** 6841-6851.
Grätzel, M. (2009) Recent advances in sensitized mesoscopic solar cells. *Accounts of Chemical Research.* 42**.** 1788-1798.
Green, M. A. (2002) Third generation photovoltaics: solar cells for 2020 and beyond. *Physica E: Low-dimensional Systems and Nanostructures.* 14**.** 65-70.
Ha, Y. H., Nikolov, N., Pollack, S. K., Mastrangelo, J., Martin, B. D. and Shashidhar, R. (2004) Towards a transparent, highly conductive poly(3,4-ethylenedioxythiophene). *Advanced Functional Materials.* 14**.** 615-622.
Hagfeldt, A., Boschloo, G., Sun, L., Kloo, L. and Pettersson, H. (2010) Dye-sensitized solar cells. *Chemical Reviews.* 110**.** 6595-6663.
Hashmi, S. G., Moehl, T., Halme, J., Ma, Y., Saukkonen, T., Yella, A., Giordano, F., Decoppet, J. D., Zakeeruddin, S. M., Lund, P. and Grätzel, M. (2014) A durable SWCNT/PET polymer foil based metal free counter electrode for flexible dye-sensitized solar cells. *Journal of Materials Chemistry A.* 2**.** 19609-19615.
He, B., Tang, Q., Wang, M., Chen, H. and Yuan, S. (2014) Robust polyaniline–graphene complex counter electrodes for efficient dye-sensitized solar cells. *ACS Applied Materials & Interfaces.* 6**.** 8230-8236.
Hegazy, A., Kinadjian, N., Sadeghimakki, B., Sivoththaman, S., Allam, N. K. and Prouzet, E. (2016) TiO_2 nanoparticles optimized for photoanodes tested in large area dye-sensitized solar cells (DSSC). *Solar Energy Materials and Solar Cells.* 153**.** 108-116.
Heo, J. H., Im, S. H., Noh, J. H., Mandal, T. N., Lim, C.-S., Chang, J. A., Lee, Y. H., Kim, H.-J., Sarkar, A., Nazeeruddinmd, K., Gratzel, M. and Seok, S. I. (2013) Efficient inorganic-organic hybrid heterojunction solar cells containing perovskite compound and polymeric hole conductors. *Nat Photon.* 7**.** 486-491.
Hodes, G. and Cahen, D. (2012) All-solid-state, semiconductor-sensitized nanoporous solar cells. *Accounts of Chemical Research.* 45**.** 705-713.
Hoffmann, M. R., Martin, S. T., Choi, W. and Bahnemann, D. W. (1995) Environmental Applications of Semiconductor Photocatalysis. *Chemical Reviews.* 95**.** 69-96.

Hosseini, M., Bagheri, R. and Najjar, R. (2011) Electropolymerization of polypyrrole and polypyrrole-ZnO nanocomposites on mild steel and its corrosion protection performance. *Journal of Applied Polymer Science.* 121**.** 3159-3166.

Hsieh, T. Y., Wei, T. C., Zhai, P., Feng, S. P., Ikegami, M. and Miyasaka, T. (2015) A room-temperature process for fabricating a nano-Pt counter electrode on a plastic substrate for efficient dye-sensitized cells. *Journal of Power Sources.* 283**.** 351-357.

Huq, T., Salmieri, S., Khan, A., Khan, R. A., Le Tien, C., Riedl, B., Fraschini, C., Bouchard, J., Uribe-Calderon, J., Kamal, M. R. and Lacroix, M. (2012) Nanocrystalline cellulose (NCC) reinforced alginate based biodegradable nanocomposite film. *Carbohydrate Polymers.* 90**.** 1757-1763.

Ito, S., Murakami, T. N., Comte, P., Liska, P., Grätzel, C., Nazeeruddin, M. K. and Grätzel, M. (2008) Fabrication of thin film dye sensitized solar cells with solar to electric power conversion efficiency over 10%. *Thin Solid Films.* 516**.** 4613-4619.

Jacob, D., Mini, P. A., Balakrishnan, A., Nair, S. V. and Subramanian, K. R. V. (2014) Electrochemical behaviour of graphene–poly (3,4-ethylenedioxythiophene) (PEDOT) composite electrodes for supercapacitor applications. *Bulletin of Materials Science.* 37**.** 61-69.

Jia, J., Wu, J., Dong, J. and Lin, J. (2015) Cobalt telluride/reduced graphene oxide using as high performance counter electrode for dye-sensitized solar cells. *Electrochimica Acta.* 185**.** 184-189.

Jiang, C., Chen, G. and Wang, X. (2012) High-conversion synthesis of poly(3,4-ethylenedioxythiophene) by chemical oxidative polymerization. *Synthetic Metals.* 162**.** 1968-1971.

Jonas, F. and Schrader, L. (1991) Conductive modifications of polymers with polypyrroles and polythiophenes. *Synthetic Metals.* 41**.** 831-836.

Jumeri, F. A., Lim, H. N., Zainal, Z., Huang, N. M., Pandikumar, A. and Lim, S. P. (2015) Dual functional reduced graphene oxide as photoanode and counter electrode in dye-sensitized solar cells and its exceptional efficiency enhancement. *Journal of Power Sources.* 293**.** 712-720.

Kakiuchi, K., Hosono, E., Kimura, T., Imai, H. and Fujihara, S. (2006) Fabrication of mesoporous ZnO nanosheets from precursor templates grown in aqueous solutions. *Journal of Sol-Gel Science and Technology.* 39**.** 63-72.

Karst, N., Rey, G., Doisneau, B., Roussel, H., Deshayes, R., Consonni, V., Ternon, C. and Bellet, D. (2011) Fabrication and characterization of a composite ZnO semiconductor as electron transporting layer in dye-sensitized solar cells. *Materials Science and Engineering: B.* 176**.** 653-659.

Kathirvel, S., Chen, H.-S., Su, C., Wang, H.-H., Li, C.-Y. and Li, W.-R. (2013) Preparation of smooth surface TiO_2 photoanode for high energy conversion efficiency in dye-sensitized solar cells. *Journal of Nanomaterials.* 2013**.** 8.

Kaur, N., Thakur, H. and Prabhakar, N. (2016) Conducting polymer and multi-walled carbon nanotubes nanocomposites based amperometric biosensor for detection of organophosphate. *Journal of Electroanalytical Chemistry.* 775**.** 121-128.

Kavan, L., Yum, J.-H., Nazeeruddin, M. K. and Grätzel, M. (2011a) Graphene nanoplatelet cathode for Co(III)/(II) mediated dye-sensitized solar cells. *ACS Nano.* 5**.** 9171-9178.

Kavan, L., Yum, J. H. and Grätzel, M. (2011b) Optically Transparent Cathode for Dye-Sensitized Solar Cells Based on Graphene Nanoplatelets. *ACS Nano.* 5**.** 165-172.

Kay, A. and Grätzel, M. (1996) Low cost photovoltaic modules based on dye sensitized nanocrystalline titanium dioxide and carbon powder. *Solar Energy Materials and Solar Cells.* 44**.** 99-117.

Kazmi, S. A., Hameed, S., Ahmed, A. S., Arshad, M. and Azam, A. (2017) Electrical and optical properties of graphene-TiO_2 nanocomposite and its applications in dye sensitized solar cells (DSSC). *Journal of Alloys and Compounds.* 691**.** 659-665.

Keothongkham, K., Pimanpang, S., Maiaugree, W., Saekow, S., Jarernboon, W. and Amornkitbamrung, V. (2012) Electrochemically deposited polypyrrole for dye-sensitized solar cell counter electrodes. *International Journal of Photoenergy.* 2012**.** 7.

Khan, J. and Arsalan, M. H. (2016) Solar power technologies for sustainable electricity generation-A review. *Renewable and Sustainable Energy Reviews.* 55**.** 414-425.

Khanmirzaei, M. H., Ramesh, S. and Ramesh, K. (2015) Polymer electrolyte based dye-sensitized solar cell with rice starch and 1-methyl-3-propylimidazolium iodide ionic liquid. *Materials & Design.* 85**.** 833-837.

Kim, H.-N. and Moon, J. H. (2012) Enhanced photovoltaic properties of Nb_2O_5-coated TiO_2 3D ordered porous electrodes in dye-sensitized solar cells. *ACS Applied Materials & Interfaces.* 4**.** 5821-5825.

Kim, H., Veerappan, G. and Park, J. H. (2014) Conducting polymer coated non-woven graphite fiber film for dye-sensitized solar cells: Superior Pt- and FTO-free counter electrodes. *Electrochimica Acta.* 137**.** 164-168.

Kubesa, O., Morrisey, K., Mathews, S., Proetta, J., Li, C., Skladal, P. and Hepel, M. (2014) Design of novel biosensors for determination of phenolic compounds using catalyst-loaded reduced graphene oxide electrodes. *Mediterranean Journal of Chemistry.* 3**.** 916-928.

Kwon, O. and Mckee, M. L. (2000) Calculations of Band Gaps in Polyaniline from Theoretical Studies of Oligomers. *The Journal of Physical Chemistry B.* 104**.** 1686-1694.

Lam, E., Male, K. B., Chong, J. H., Leung, A. C. W. and Luong, J. H. T. (2012) Applications of functionalized and nanoparticle-modified nanocrystalline cellulose. *Trends in Biotechnology.* 30**.** 283-290.

Lee, C., Wei, X., Kysar, J. W. and Hone, J. (2008) Measurement of the elastic properties and intrinsic strength of monolayer graphene. *Science.* 321**.** 385.

Lee, K.-W., Kim, M., Kim, J.-M., Kim, J. J. and Lee, I.-H. (2016) Enhanced photovoltaic performance of back-illuminated dye-sensitized solar cell based on TiO_2 nanoparticle/nanowire composite film in cobalt redox system. *Journal of Alloys and Compounds.* 656**.** 568-572.

Lee, K. M., Chen, P. Y., Hsu, C. Y., Huang, J. H., Ho, W. H., Chen, H. C. and Ho, K. C. (2009a) A high-performance counter electrode based on poly(3,4-alkylenedioxythiophene) for dye-sensitized solar cells. *Journal of Power Sources.* 188**.** 313-318.

Lee, K. S., Lee, H. K., Wang, D. H., Park, N.-G., Lee, J. Y., Park, O. O. and Park, J. H. (2010a) Dye-sensitized solar cells with Pt- and TCO-free counter electrodes. *Chemical Communications.* 46**.** 4505-4507.

Lee, K. S., Lee, Y., Lee, J. Y., Ahn, J. H. and Park, J. H. (2012) Flexible and platinum-free dye-sensitized solar cells with conducting-polymer-coated graphene counter electrodes. *ChemSusChem.* 5**.** 379-382.

Lee, W. J., Ramasamy, E., Lee, D. Y. and Song, J. S. (2009b) Efficient dye-sensitized solar cells with catalytic multiwall carbon nanotube counter electrodes. *ACS Applied Materials & Interfaces.* 1**.** 1145-1149.

Lee, Y.-L., Chen, C.-L., Chong, L.-W., Chen, C.-H., Liu, Y.-F. and Chi, C.-F. (2010b) A platinum counter electrode with high electrochemical activity and high transparency for dye-sensitized solar cells. *Electrochemistry Communications.* 12**.** 1662-1665.

Lee, Y. L., Chen, C. L., Chong, L. W., Chen, C. H., Liu, Y. F. and Chi, C. F. (2010c) A platinum counter electrode with high electrochemical activity and high transparency for dye-sensitized solar cells. *Electrochemistry Communications.* 12**.** 1662-1665.

Li, B., Wang, L., Kang, B., Wang, P. and Qiu, Y. (2006) Review of recent progress in solid-state dye-sensitized solar cells. *Solar Energy Materials and Solar Cells.* 90**.** 549-573.

Li, D., Qin, D., Deng, M., Luo, Y. and Meng, Q. (2009a) Optimization the solid-state electrolytes for dye-sensitized solar cells. *Energy & Environmental Science.* 2**.** 283-291.

Li, P., Wu, J., Lin, J., Huang, M., Lan, Z. and Li, Q. (2008a) Improvement of performance of dye-sensitized solar cells based on electrodeposited-platinum counter electrode. *Electrochimica Acta.* 53**.** 4161-4166.

Li, Q., Tang, Q., He, B. and Yang, P. (2014) Full-ionic liquid gel electrolytes: Enhanced photovoltaic performances in dye-sensitized solar cells. *Journal of Power Sources.* 264**.** 83-91.

Li, Q., Wu, J., Tang, Q., Lan, Z., Li, P., Lin, J. and Fan, L. (2008b) Application of microporous polyaniline counter electrode for dye-sensitized solar cells. *Electrochemistry Communications.* 10**.** 1299-1302.

Li, Q., Zhou, J. and Zhang, L. (2009b) Structure and properties of the nanocomposite films of chitosan reinforced with cellulose whiskers. *Journal of Polymer Science Part B: Polymer Physics.* 47**.** 1069-1077.

Li, R., Tang, Q., Yu, L., Yan, X., Zhang, Z. and Yang, P. (2016) Counter electrodes from conducting polymer intercalated graphene for dye-sensitized solar cells. *Journal of Power Sources.* 309**.** 231-237.

Li, S.-S., Tu, K.-H., Lin, C.-C., Chen, C.-W. and Chhowalla, M. (2010) Solution-processable graphene oxide as an efficient hole transport layer in polymer solar cells. *ACS Nano.* 4**.** 3169-3174.

Li, Z., Ye, B., Hu, X., Ma, X., Zhang, X. and Deng, Y. (2009c) Facile electropolymerized-PANI as counter electrode for low cost dye-sensitized solar cell. *Electrochemistry Communications.* 11**.** 1768-1771.

Lian, K.-Y., Ji, Y.-F., Li, X.-F., Jin, M.-X., Ding, D.-J. and Luo, Y. (2013) Big Bandgap in Highly Reduced Graphene Oxides. *The Journal of Physical Chemistry C.* 117**.** 6049-6054.

Liao, Y., Pan, K., Wang, L., Pan, Q., Zhou, W., Miao, X., Jiang, B., Tian, C., Tian, G. and Wang, G. (2013) Facile synthesis of high-crystallinity graphitic carbon/Fe_3C nanocomposites as counter electrodes for high-efficiency dye-sensitized solar cells. *ACS applied materials & interfaces.* 5**.** 3663-3670.

Lin, C. P., Chen, H., Nakaruk, A., Koshy, P. and Sorrell, C. C. (2013) Effect of annealing temperature on the photocatalytic activity of TiO_2 thin films. *Energy Procedia.* 34**.** 627-636.

Lin, X., Wu, M., Wang, Y., Hagfeldt, A. and Ma, T. (2011) Novel counter electrode catalysts of niobium oxides supersede Pt for dye-sensitized solar cells. *Chemical Communications.* 47**.** 11489-11491.

Liu, S., Han, L., Duan, Y., Asahina, S., Terasaki, O., Cao, Y., Liu, B., Ma, L., Zhang, J. and Che, S. (2012) Synthesis of chiral TiO_2 nanofibre with electron transition-based optical activity. *Nature Communications.* 3.

Liu, Z., Li, Y., Liu, C., Ya, J., Zhao, W., E, L., Zhao, D. and An, L. (2011) Performance of ZnO dye-sensitized solar cells with various nanostructures as anodes. *Solid State Sciences.* 13**.** 1354-1359.

Lu, S., Zhang, X., Feng, T., Han, R., Liu, D. and He, T. (2015) Preparation of polypyrrole thin film counter electrode with pre-stored iodine and resultant influence on its performance. *Journal of Power Sources.* 274**.** 1076-1084.

Maiaugree, W., Lowpa, S., Towannang, M., Rutphonsan, P., Tangtrakarn, A., Pimanpang, S., Maiaugree, P., Ratchapolthavisin, N., Sang-Aroon, W., Jarernboon, W. and Amornkitbamrung, V. (2015) A dye sensitized solar cell using natural counter electrode and natural dye derived from mangosteen peel waste. 5**.** 15230.

Maiaugree, W., Pimparue, P., Jarernboon, W., Pimanpang, S., Amornkitbamrung, V. and Swatsitang, E. (2017) NiS(NPs)-PEDOT-PSS composite counter electrode for a high efficiency dye sensitized solar cell. *Materials Science and Engineering: B.* 220**.** 66-72.

Martinson, A. B. F., Góes, M. S., Fabregat-Santiago, F., Bisquert, J., Pellin, M. J. and Hupp, J. T. (2009) Electron transport in dye-sensitized solar cells based on ZnO nanotubes: evidence for highly efficient charge collection and exceptionally rapid dynamics. *The Journal of Physical Chemistry A.* 113**.** 4015-4021.

Mokrane, S., Makhloufi, L. and Alonso-Vante, N. (2008) Electrochemistry of platinum nanoparticles supported in polypyrrole (PPy)/C composite materials. *Journal of Solid State Electrochemistry.* 12**.** 569-574.

Murakami, T. N. and Grätzel, M. (2008) Counter electrodes for DSC: Application of functional materials as catalysts. *Inorganica Chimica Acta.* 361**.** 572-580.

N, E., G, G., S, A., P, R. and P, R. (2017) Effect of tin oxide crystallite size on the efficacy of polyaniline-tin oxide nanocomposite based counter electrode for DSSC applications. *Optik - International Journal for Light and Electron Optics.* 142**.** 436-445.

Nagavolu, C., Susmitha, K., Raghavender, M., Giribabu, L., Bhanu Sankara Rao, K., Smith, C. T. G., Mills, C. A., Silva, S. R. P. and Srikanth, V. V. S. S. (2016) Pt-free spray coated reduced graphene oxide counter electrodes for dye sensitized solar cells. *Solar Energy.* 137**.** 143-147.

Nair, R. R., Blake, P., Grigorenko, A. N., Novoselov, K. S., Booth, T. J., Stauber, T., Peres, N. M. R. and Geim, A. K. (2008) Fine structure constant defines visual transparency of graphene. *Science.* 320**.** 1308.

Nazeeruddin, M. K., Kay, A., Rodicio, I., Humphry-Baker, R., Müller, E., Liska, P., Vlachopoulos, N. and Grätzel, M. (1993) Conversion of light to electricity by cis-X_2bis(2,2′-bipyridyl-4,4′-dicarboxylate)ruthenium(II) charge-transfer sensitizers (X = Cl^-, Br^-, I^-, CN^-, and SCN^-) on nanocrystalline TiO_2 electrodes. *Journal of the American Chemical Society.* 115**.** 6382-6390.

Novoselov, K. S., Geim, A. K., Morozov, S. V., Jiang, D., Zhang, Y., Dubonos, S. V., Grigorieva, I. V. and Firsov, A. A. (2004) Electric field effect in atomically thin carbon films. *Science.* 306**.** 666.

O'regan, B. and Gratzel, M. (1991) A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films. *Nature.* 353**.** 737-740.

O’regan, B. and Grätzel, M. (1991) A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films. *Nature.* 353**.** 737-740.

Park, J.-G., Akhtar, M. S., Li, Z. Y., Cho, D.-S., Lee, W. and Yang, O. B. (2012) Application of single walled carbon nanotubes as counter electrode for dye sensitized solar cells. *Electrochimica Acta.* 85**.** 600-604.

Paterakis, G., Raptis, D., Ploumistos, A., Belekoukia, M., Sygellou, L., Ramasamy, M. S., Lianos, P. and Tasis, D. (2017) N-Doped graphene/PEDOT composite films as counter electrodes in DSSCs: Unveiling the mechanism of electrocatalytic activity enhancement. *Applied Surface Science.* 423**.** 443-450.

Patra, A. and Bendikov, M. (2010) Polyselenophenes. *Journal of Materials Chemistry.* 20**.** 422-433.

Peigney, A., Laurent, C., Flahaut, E., Bacsa, R. and Rousset, A. (2001a) Specific surface area of carbon nanotubes and bundles of carbon nanotubes. *Carbon.* 39**.** 507-514.

Peigney, A., Laurent, C., Flahaut, E., Bacsa, R. R. and Rousset, A. (2001b) Specific surface area of carbon nanotubes and bundles of carbon nanotubes. *Carbon.* 39**.** 507-514.

Peponi, L., Puglia, D., Torre, L., Valentini, L. and Kenny, J. M. (2014) Processing of nanostructured polymers and advanced polymeric based nanocomposites. *Materials Science and Engineering: R: Reports.* 85**.** 1-46.

Poverenov, E., Sheynin, Y., Zamoshchik, N., Patra, A., Leitus, G., Perepichka, I. F. and Bendikov, M. (2012) Flat conjugated polymers combining a relatively low HOMO energy level and band gap: polyselenophenes versus polythiophenes. *Journal of Materials Chemistry.* 22**.** 14645-14655.

Pullanjiyot, N., Manakkulamparambil Vidyadharan, D. and Swaminathan, S. (2016) Synthesis and electrochemical characterization of physically cross-linked gel electrolyte for QSDSSC application. *Materials & Design.* 101**.** 270-276.

Quintana, M., Edvinsson, T., Hagfeldt, A. and Boschloo, G. (2007) Comparison of dye-sensitized ZnO and TiO_2 solar cells: studies of charge transport and carrier lifetime. *The Journal of Physical Chemistry C.* 111**.** 1035-1041.

Ragoussi, M.-E. and Torres, T. (2015) New generation solar cells: concepts, trends and perspectives. *Chemical Communications.* 51**.** 3957-3972.

Ramana, G. V., Srikanth, V. V. S. S., Padya, B. and Jain, P. K. (2014) Carbon nanotube–polyaniline nanotube core–shell structures for electrochemical applications. *European Polymer Journal.* 57**.** 137-142.

Ramasamy, E., Lee, W. J., Lee, D. Y. and Song, J. S. (2008) Spray coated multi-wall carbon nanotube counter electrode for tri-iodide reduction in dye-sensitized solar cells. *Electrochemistry Communications.* 10**.** 1087-1089.

Rodríguez-Moreno, J., Navarrete-Astorga, E., Martín, F., Schrebler, R., Ramos-Barrado, J. R. and Dalchiele, E. A. (2012) Semitransparent ZnO/poly(3,4-ethylenedioxythiophene) based hybrid inorganic/organic heterojunction thin film diodes prepared by combined radio-frequency magnetron-sputtering and electrodeposition techniques. *Thin Solid Films.* 525**.** 88-92.

Roy-Mayhew, J. D., Bozym, D. J., Punckt, C. and Aksay, I. A. (2010) Functionalized graphene as a catalytic counter electrode in dye-sensitized solar cells. *ACS Nano.* 4**.** 6203-6211.

Sahito, I. A., Sun, K. C., Arbab, A. A., Qadir, M. B., Choi, Y. S. and Jeong, S. H. (2016) Flexible and conductive cotton fabric counter electrode coated with graphene nanosheets for high efficiency dye sensitized solar cell. *Journal of Power Sources.* 319**.** 90-98.

Saito, Y., Kitamura, T., Wada, Y. and Yanagida, S. (2002) Application of poly (3, 4-ethylenedioxythiophene) to counter electrode in dye-sensitized solar cells. *Chemistry Letters.* 31**.** 1060-1061.

Samadi, M., Shivaee, H. A., Zanetti, M., Pourjavadi, A. and Moshfegh, A. (2012) Visible light photocatalytic activity of novel MWCNT-doped ZnO electrospun nanofibers. *Journal of Molecular Catalysis A: Chemical.* 359**.** 42-48.

Sekkarapatti Ramasamy, M., Nikolakapoulou, A., Raptis, D., Dracopoulos, V., Paterakis, G. and Lianos, P. (2015) Reduced graphene oxide/Polypyrrole/PEDOT composite films as efficient Pt-free counter electrode for dye-sensitized solar cells. *Electrochimica Acta.* 173**.** 276-281.

Sharifi, N., Tajabadi, F. and Taghavinia, N. (2014) Recent Developments in Dye-Sensitized Solar Cells. *ChemPhysChem.* 15**.** 3902-3927.

Shin, H.-J., Jeon, S. S. and Im, S. S. (2011) CNT/PEDOT core/shell nanostructures as a counter electrode for dye-sensitized solar cells. *Synthetic Metals.* 161**.** 1284-1288.

Shin, Y. and Exarhos, G. J. (2007) Template synthesis of porous titania using cellulose nanocrystals. *Materials Letters.* 61**.** 2594-2597.

Si, P., Ding, S., Lou, X.-W. and Kim, D.-H. (2011) An electrochemically formed three-dimensional structure of polypyrrole/graphene nanoplatelets for high-performance supercapacitors. *RSC Advances.* 1**.** 1271-1278.

Skotheim, T. A. and Reynolds, J. (2007) *Handbook of Conducting Polymers, 2 Volume Set.* CRC press.

Sobuś, J., Burdziński, G., Karolczak, J., Idígoras, J., Anta, J. A. and Ziółek, M. (2014) Comparison of TiO_2 and ZnO solar cells sensitized with an indoline dye: time-resolved laser spectroscopy studies of partial charge separation processes. *Langmuir.* 30**.** 2505-2512.

Stankovich, S., Dikin, D. A., Dommett, G. H. B., Kohlhaas, K. M., Zimney, E. J., Stach, E. A., Piner, R. D., Nguyen, S. T. and Ruoff, R. S. (2006) Graphene-based composite materials. *Nature.* 442**.** 282-286.

Stankovich, S., Dikin, D. A., Piner, R. D., Kohlhaas, K. A., Kleinhammes, A., Jia, Y., Wu, Y., Nguyen, S. T. and Ruoff, R. S. (2007) Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide. *Carbon.* 45**.** 1558-1565.

Su, S., Zhang, H., Chen, X., Kang, J. and Chen, J. (2013) Parametric optimum design of a photon-enhanced thermionic solar cell. *Solar Energy Materials and Solar Cells.* 117**.** 219-224.

Syed Zainol Abidin, S. N. J., Azman, N. H. N., Kulandaivalu, S. and Sulaiman, Y. (2017) Poly(3,4-ethylenedioxythiophene) doped with carbon materials for high-performance supercapacitor: a comparison study. *Journal of Nanomaterials.* 2017**.** 1-13.

Takada, H., Obana, Y., Sasaki, R., Kuribayashi, M., Kanno, M., Zhu, C., Bessho, T., Takagi, Y., Hinokuma, K. and Noda, K. (2015) Improved durability of dye-sensitized solar cell with H_2-reduced carbon counter electrode. *Journal of Power Sources.* 274**.** 1276-1282.

Tanaka, Y., Hirana, Y., Niidome, Y., Kato, K., Saito, S. and Nakashima, N. (2009) Experimentally Determined Redox Potentials of Individual (n,m) Single-Walled Carbon Nanotubes. *Angewandte Chemie International Edition.* 48**.** 7655-7659.

Tang, Q., Cai, H., Yuan, S. and Wang, X. (2013) Counter electrodes from double-layered polyaniline nanostructures for dye-sensitized solar cell applications. *Journal of Materials Chemistry A.* 1**.** 317-323.

Thomas, S., Deepak, T. G., Anjusree, G. S., Arun, T. A., Nair, S. V. and Nair, A. S. (2014) A review on counter electrode materials in dye-sensitized solar cells. *Journal of Materials Chemistry A.* 2**.** 4474-4490.

Tian, H.-C., Liu, J.-Q., Wei, D.-X., Kang, X.-Y., Zhang, C., Du, J.-C., Yang, B., Chen, X., Zhu, H.-Y. and Nuli, Y.-N. (2014) Graphene oxide doped conducting polymer nanocomposite film for electrode-tissue interface. *Biomaterials.* 35**.** 2120-2129.

Umar, A. (2009) Growth of comb-like ZnO nanostructures for dye-sensitized solar cells applications. *Nanoscale Research Letters.* 4**.** 1004 - 1008.

Velasco-Soto, M. A., Pérez-García, S. A., Alvarez-Quintana, J., Cao, Y., Nyborg, L. and Licea-Jiménez, L. (2015) Selective band gap manipulation of graphene oxide by its reduction with mild reagents. *Carbon.* 93**.** 967-973.

Wahab, R., Ansari, S. G., Kim, Y. S., Seo, H. K., Kim, G. S., Khang, G. and Shin, H.-S. (2007) Low temperature solution synthesis and characterization of ZnO nano-flowers. *Materials Research Bulletin.* 42**.** 1640-1648.

Wang, G., Cai, Z., Li, F., Tan, S., Xie, S. and Li, J. (2014) 2% ZnO increases the conversion efficiency of TiO_2 based dye sensitized solar cells by 12%. *Journal of Alloys and Compounds.* 583**.** 414-418.

Wang, H.-Y., Wang, F.-M., Wang, Y.-Y., Wan, C.-C., Hwang, B.-J., Santhanam, R. and Rick, J. (2011) Electrochemical formation of Pt nanoparticles on multiwalled carbon nanotubes: useful for fabricating electrodes for use in dye-sensitized solar cells. *The Journal of Physical Chemistry C.* 115**.** 8439-8446.

Wang, K.-P. and Teng, H. (2009) Zinc-doping in TiO_2 films to enhance electron transport in dye-sensitized solar cells under low-intensity illumination. *Physical Chemistry Chemical Physics.* 11**.** 9489-9496.

Wang, L.-X., Li, X.-G. and Yang, Y.-L. (2001) Preparation, properties and applications of polypyrroles. *Reactive and Functional Polymers.* 47**.** 125-139.

Wang, M., Gratzel, C., Zakeeruddin, S. M. and Gratzel, M. (2012) Recent developments in redox electrolytes for dye-sensitized solar cells. *Energy & Environmental Science.* 5**.** 9394-9405.

Welsh, D. M., Kloeppner, L. J., Madrigal, L., Pinto, M. R., Thompson, B. C., Schanze, K. S., Abboud, K. A., Powell, D. and Reynolds, J. R. (2002) Regiosymmetric dibutyl-substituted poly(3,4-propylenedioxythiophene)s as highly electron-rich electroactive and luminescent polymers. *Macromolecules.* 35**.** 6517-6525.

Wright, M. and Uddin, A. (2012) Organic-inorganic hybrid solar cells: A comparative review. *Solar Energy Materials and Solar Cells.* 107**.** 87-111.

Wu, J., Lan, Z., Hao, S., Li, P., Lin, J., Huang, M., Fang, L. and Huang, Y. (2008) Progress on the electrolytes for dye-sensitized solar cells. *Pure and Applied Chemistry.*

Wu, J., Lan, Z., Lin, J., Huang, M., Huang, Y., Fan, L. and Luo, G. (2015) Electrolytes in dye-sensitized solar cells. *Chemical Reviews.* 115**.** 2136-2173.

Wu, M., Lin, X., Wang, Y., Wang, L., Guo, W., Qi, D., Peng, X., Hagfeldt, A., Grätzel, M. and Ma, T. (2012) Economical Pt-free catalysts for counter electrodes of dye-sensitized solar cells. *Journal of the American Chemical Society.* 134**.** 3419-3428.

Xia, J., Chen, L. and Yanagida, S. (2011) Application of polypyrrole as a counter electrode for a dye-sensitized solar cell. *Journal of Materials Chemistry.* 21**.** 4644-4649.

Xia, J., Masaki, N., Jiang, K. and Yanagida, S. (2007) The influence of doping ions on poly(3,4-ethylenedioxythiophene) as a counter electrode of a dye-sensitized solar cell. *Journal of Materials Chemistry.* 17**.** 2845-2850.

Xu, C., Li, J., Wang, X., Wang, J., Wan, L., Li, Y., Zhang, M., Shang, X. and Yang, Y. (2012) Synthesis of hemin functionalized graphene and its application as a

counter electrode in dye-sensitized solar cells. *Materials Chemistry and Physics.* 132**.** 858-864.
Xu, X., Huang, D., Cao, K., Wang, M., Zakeeruddin, S. M. and Grätzel, M. (2013) Electrochemically reduced graphene oxide multilayer films as efficient counter electrode for dye-sensitized solar cells. *Scientific Reports.* 3**.** 1489-1495.
Yadav, A. T., Magar, P. P., Kadam, V. S., Jagtap, C. V. and Pawar, C. S. (2016) Chemically deposited nickel oxide as counter electrode for dye sensitized solar cell. *Journal of Materials Science: Materials in Electronics.* 27**.** 12297-12301.
Yang, C.-C., Zhang, H. Q. and Zheng, Y. R. (2011) DSSC with a novel Pt counter electrodes using pulsed electroplating techniques. *Current Applied Physics.* 11**.** S147-S153.
Ye, M., Wen, X., Wang, M., Iocozzia, J., Zhang, N., Lin, C. and Lin, Z. (2015) Recent advances in dye-sensitized solar cells: from photoanodes, sensitizers and electrolytes to counter electrodes. *Materials Today.* 18**.** 155-162.
Ye, S., Jin, W., Huang, Q., Hu, Y., Li, Y., Li, J. and Li, B. (2017) Da-KGM based GO-reinforced FMBO-loaded aerogels for efficient arsenic removal in aqueous solution. *International Journal of Biological Macromolecules.* 94, Part A**.** 527-534.
Yeh, M.-H., Lin, L.-Y., Chang, L.-Y., Leu, Y.-A., Cheng, W.-Y., Lin, J.-J. and Ho, K.-C. (2014) Dye-sensitized solar cells with reduced graphene oxide as the counter electrode prepared by a green photothermal reduction process. *ChemPhysChem.* 15**.** 1175-1181.
Yeh, M. H., Lee, C. P., Chou, C. Y., Lin, L. Y., Wei, H. Y., Chu, C. W., Vittal, R. and Ho, K. C. (2011) Conducting polymer-based counter electrode for a quantum-dot-sensitized solar cell (QDSSC) with a polysulfide electrolyte. *Electrochim Acta.* 57.
Yohannes, T. and Inganäs, O. (1998) Photoelectrochemical studies of the junction between poly[3-(4-octylphenyl)thiophene] and a redox polymer electrolyte. *Solar Energy Materials and Solar Cells.* 51**.** 193-202.
Yoon, C. H., Vittal, R., Lee, J., Chae, W. S. and Kim, K. J. (2008) Enhanced performance of a dye-sensitized solar cell with an electrodeposited-platinum counter electrode. *Electrochimica Acta.* 53**.** 2890-2896.
Yoon, D. H., Yoon, S. H., Ryu, K.-S. and Park, Y. J. (2016) PEDOT:PSS as multi-functional composite material for enhanced Li-air-battery air electrodes. *Scientific Reports.* 6**.** 19962.
Yu, J. C., Zhang, L., Zheng, Z. and Zhao, J. (2003) Synthesis and characterization of phosphated mesoporous titanium dioxide with high photocatalytic activity. *Chemistry of Materials.* 15**.** 2280-2286.
Yu, Z., Li, F. and Sun, L. (2015) Recent advances in dye-sensitized photoelectrochemical cells for solar hydrogen production based on molecular components. *Energy & Environmental Science.* 8**.** 760-775.
Yun, S., Freitas, J. N., Nogueira, A. F., Wang, Y., Ahmad, S. and Wang, Z.-S. (2015) Dye-sensitized solar cells employing polymers. *Progress in Polymer Science.*
Zaban, A., Meier, A. and Gregg, B. A. (1997) Electric potential distribution and short-range screening in nanoporous TiO_2 electrodes. *The Journal of Physical Chemistry B.* 101**.** 7985-7990.
Zhang, J., Hreid, T., Li, X., Guo, W., Wang, L., Shi, X., Su, H. and Yuan, Z. (2010a) Nanostructured polyaniline counter electrode for dye-sensitised solar cells:

Fabrication and investigation of its electrochemical formation mechanism. *Electrochimica Acta.* 55**.** 3664-3668.

Zhang, J., Yang, H., Shen, G., Cheng, P., Zhang, J. and Guo, S. (2010b) Reduction of graphene oxide vial-ascorbic acid. *Chemical Communications.* 46**.** 1112-1114.

Zhang, L., Jamal, R., Zhao, Q., Wang, M. and Abdiryim, T. (2015) Preparation of PEDOT/GO, PEDOT/MnO(2), and PEDOT/GO/MnO(2) nanocomposites and their application in catalytic degradation of methylene blue. *Nanoscale Research Letters.* 10**.** 148.

Zhang, P., Fujitsuka, M. and Majima, T. (2016) TiO_2 mesocrystal with nitrogen and fluorine codoping during topochemical transformation: Efficient visible light induced photocatalyst with the codopants. *Applied Catalysis B: Environmental.* 185**.** 181-188.

Zhao, Q., Jamal, R., Zhang, L., Wang, M. and Abdiryim, T. (2014a) The structure and properties of PEDOT synthesized by template-free solution method. *Nanoscale Research Letters.* 9**.** 557.

Zhao, X., Li, M., Song, D., Cui, P., Zhang, Z., Zhao, Y., Shen, C. and Zhang, Z. (2014b) A novel hierarchical Pt- and FTO-free counter electrode for dye-sensitized solar cell. *Nanoscale Research Letters.* 9**.** 202-202.

Zheng, M., Huo, J., Tu, Y., Wu, J., Hu, L. and Dai, S. (2015) Flowerlike molybdenum sulfide/multi-walled carbon nanotube hybrid as Pt-free counter electrode used in dye-sensitized solar cells. *Electrochimica Acta.* 173**.** 252-259.

Zhou, H., Shi, Y., Qin, D., An, J., Chu, L., Wang, C., Wang, Y., Guo, W., Wang, L. and Ma, T. (2013a) Printable fabrication of Pt-and-ITO free counter electrodes for completely flexible quasi-solid dye-sensitized solar cells. *Journal of Materials Chemistry A.* 1**.** 3932-3937.

Zhou, Y., Fuentes-Hernandez, C., Khan, T. M., Liu, J.-C., Hsu, J., Shim, J. W., Dindar, A., Youngblood, J. P., Moon, R. J. and Kippelen, B. (2013b) Recyclable organic solar cells on cellulose nanocrystal substrates. *Scientific Reports.* 3**.** 1536-1540.

Zhu, Q.-G., Sujari, A. N. A. and Ab Ghani, S. (2013) MWCNT modified composite pencil graphite electrodes fabricated by direct dripping and electrophoretic deposition methods: a comparison study. *Journal of The Electrochemical Society.* 160**.** B23-B29.

Zhu, W. K., Cong, H. P., Yao, H. B., Mao, L. B., Asiri, A. M., Alamry, K. A., Marwani, H. M. and Yu, S. H. (2015) Bioinspired, ultrastrong, highly biocompatible, and bioactive natural polymer/graphene oxide nanocomposite films. *Small.* 11**.** 4298-4302.

LIST OF PUBLICATIONS

Mustafa, M., Shafie, S., Zainal, Z. and Sulaiman, Y. (2017a) *A Novel Poly(3,4-ethylenedioxythiophene)-graphene Oxide/Titanium Dioxide Composites Counter Electrode for Dye-Sensitized Solar Cell.*

Mustafa, M., Shafie, S., Zainal, Z. and Sulaiman, Y. (2017b) *Poly(3,4-ethylenedioxythiophene) doped with various carbon-based materials as counter electrodes for dye sensitized solar cells.*