UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF TITANIUM DIOXIDE BASED COMPACT LAYERS AND LIGHT SCATTERING LAYERS FOR ENHANCED DYE-SENSITIZED SOLAR CELL

MUHAMMAD NORHAFFIS BIN MUSTAFA

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By

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Chairman : Associate Professor Yusran Sulaiman, PhD
Faculty : Science

Dye-sensitized solar cells (DSSCs) are the third-generation solar cell that capable of converting solar energy into electrical energy. Titanium dioxide (TiO_2) as a photoanode has faced a lot of drawbacks such as low dye loading capacity, a small range of light scattering, high recombination effect and low charge transport ability that subsequently reduces its power conversion efficiency (PCE). In this work, the enhancement of DSSC performance was studied by the modification of photoanode, specifically on the fabrication of a new compact layer (CL) and light scattering layers (LSLs). A dense, compact and homogenous TiO_2 CL was optimized and prepared using response surface methodology by central composite design (RSM/CCD) and heat treatment assisted electrospinning, respectively. The TiO_2 CL was successfully optimized with less than 5% residual standard error (RSE) and capable of enhancing the PCE up to 76.88% compared with the bare photoanode (1.73%). This is due to an improved electron lifetime (τ_n) and charge collection efficiency (η_c), resulting in a low recombination effect that leads to a higher PCE. Two LSLs were prepared in this study, namely polyvinyl alcohol (PVA/TiO_2) nanofibers and TiO_2 decorated by graphene quantum dot (TiO_2-GQD). The PVA/TiO_2 was prepared using electrospinning while TiO_2-GQD was prepared via electrodeposition and drop-casting technique. Both PVA/TiO_2 nanofibers and TiO_2-GQD LSLs were successfully optimized using RSM/CCD with less than 5% RSE. Upon the addition of TiO_2-GQD LSL onto the photoanode, the PCE increased up to 5.01% compared to the photoanode with PVA/TiO_2 nanofibers LSL (4.06%) and bare photoanode (3.06%). This increment is due to the longer τ_n, higher η_c, higher dye loading capacity and higher light reflectance, demonstrating a good light scattering material. Furthermore, a fully flexible photoanode with TiO_2-GQD LSL has successfully fabricated on indium doped tin oxide/polyethylene naphthalate (ITO/PEN) flexible substrate via electrodeposition and drop-casting technique. The fully flexible DSSC device consisting of photoanode with TiO_2-GQD LSL

showed an enhanced PCE of 5.18% compared to the bare photoanode (2.65%). The vast enhancement of PCE was due to the increase in the dye loading capacity (more dye can be adsorbed) and light scattering ability (more light can be scattered) upon the addition of TiO_2-GQD LSL. In a nutshell, the introduction of CL and LSLs has successfully increased the DSSC performance.

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PEMBANGUNAN LAPISAN KOMPAK DAN LAPISAN PENYERAKKAN CAHAYA BERDASARKAN TITANIUM DIOKSIDA UNTUK SEL SOLAR BERKEPEKAAN PEWARNA YANG DITINGKATKAN

Oleh

MUHAMMAD NORHAFFIS BIN MUSTAFA

Ogos 2020

Pengerusi : Profesor Madya Yusran Sulaiman, PhD
Fakulti : Sains

Sel solar berkepekaan pewarna (DSSCs) ialah generasi ketiga sel solar yang mampu menukarkan tenaga solar kepada tenaga elektrik. Titanium dioksida (TiO_2) sebagai fotoanod telah mengalami banyak masalah seperti kapasiti pemuatan pewarna yang rendah, julat penyerakkan cahaya yang kecil, kesan penggabungan yang tinggi dan keupayaan pengangkutan caj yang rendah dan seterusnya mengurangkan kecekapan penukaran kuasanya (PCE). Dalam kajian ini, peningkatan prestasi DSSC dikaji dengan pengubahsuaian fotoanod, khususnya pada penghasilan baru lapisan padat (CL) dan lapisan penyerakkan cahaya (LSLs). CL TiO_2 yang padat dan homogen dioptimumkan dan disediakan masing-masing dengan menggunakan metodologi permukaan tindak balas dengan reka bentuk komposit pusat (RSM/CCD) dan elektroputaran dibantu rawatan haba. CL TiO_2 berjaya dioptimumkan dengan baki ralat standard (RSE) kurang dari 5% dan mampu meningkatkan PCE sehingga 76.88% berbanding dengan fotoanod pengosong (1.73%). Hal ini disebabkan oleh peningkatan jangka hayat elektron (τ_n) dan kecekapan pengumpulan caj (η_c), menghasilkan kesan penggabungan yang rendah yang membawa kepada PCE yang lebih tinggi. Dua LSL disediakan di dalam kajian ini iaitu nanofiber poli(vinil alkohol)/titanium dioksida (PVA/TiO_2) dan TiO_2 dihiasi dengan titik kuantum grafin (TiO_2-GQD). Nanofiber PVA/TiO_2 telah dihasilkan melalui elektroputaran manakala TiO_2-GQD telah dihasilkan melalui elektroenapan dan kaedah penyalutan titis. Kedua-dua LSL nanofiber PVA/TiO_2 dan TiO_2-GQD telah berjaya dioptimumkan menggunakan RSM/CCD dengan RSE kurang dari 5%. Setelah penambahan TiO_2-GQD LSL ke atas fotoanod, PCE telah meningkat sehingga 5.01% berbanding fotoanod dengan PVA/TiO_2 nanofibers LSL (4.06%) dan fotoanod pengosong (3.06%). Peningkatan ini disebabkan oleh τ_n yang lebih lama, η_c yang lebih tinggi, kapasiti pemuatan pewarna yang lebih tinggi dan pantulan cahaya yang lebih tinggi, menunjukkan ciri-ciri bahan penyerakan cahaya yang baik. Selanjutnya, fotoanod fleksibel sepenuhnya dengan TiO_2-GQD LSL telah berjaya disediakan pada substrat fleksibel indium timah oksida/polietilena naftalat (ITO/PEN) melalui elektroenapan dan kaedah penyalutan titis. Peranti DSSC yang fleksibel sepenuhnya terdiri daripada fotoanod dengan LSL TiO_2-GQD menunjukkan peningkatan PCE sebanyak 5.18% berbanding dengan fotoanod pengosong (2.65%). Peningkatan PCE yang sangat besar adalah disebabkan oleh peningkatan kapasiti pemuatan pewarna (lebih banyak pewarna boleh dijerap) dan kemampuan penyerakan cahaya (lebih banyak cahaya boleh diserakkan) setelah penambahan LSL TiO_2-GQD. Kesimpulannya, penambahan CL dan LSL telah berjaya meningkatkan prestasi DSSC.

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- Anna Taylor -

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

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

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

Mohd Haniff Wahid, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

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Name of Chairman of Supervisory Committee: Yusran Sulaiman

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

Signature: ____________________________
Name of Member of Supervisory Committee: Mohd Haniff Wahid

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Symbol	Meaning	Unit
OCP	Open circuit voltage	V
P_{in}	Power input	$mW.cm^{-2}$
P_{max}	Maximum power	mW
J_{sc}	Short circuit current	$mA.cm^{-2}$
V_{oc}	Open circuit voltage	V
R_{ct}	Charge transfer resistance	Ω
R_s	Series resistance	Ω
CPE	Constant phase element	F
Z′	Real impedance	Ω
Z″	Imaginary impedance	Ω
E_{pp}	Peak to peak separation	V
η_c	Charce collection efficiency	%
PCE	Power conversion efficiency	%
τ_n	Electron lifetime	ms
λ	Wavelength	nm
RSE	Residual standard error	%
FF	Fill factor	%
J_{max}	Maximum current	mA
V_{max}	Maximum voltage	V

LIST OF ABBREVIATIONS

AACVD	Aerosol assisted chemical vapor deposition
ATR	Attenuated total reflection
BET	Brunauer–Emmett–Teller
CLs	Compact layers
CO_2	Carbon dioxide
D	Dye molecules
D^+	Hole of dye molecules
DSSCs	Dye-sensitized solar cells
e^-	Electron
EIS	Electrochemical impedance spectroscopy
Eu^{3+}	Europium ion
F^-	Fluoride
FESEM	Field emission scanning electron microscopy
FTIR	Fourier transform infrared spectroscopy
FTO	Fluorine doped tin oxide
GO	Graphene oxide
GQD	Graphene quantum dot
GW	Gigawatts
HFs	Hollow fibers
IEA	International energy agency
IRENA	International renewable energy agency
ITO	Indium doped tin oxide
ITO/PEN	Indium doped tin oxide/polyethylene naphthalate
LSL	Light scattering layer
MRs	Micro rods

Nb	Niobium
Nb_2O_5	Niobium pentoxide
NFs	Nanofibers
NiTDP	Nickel doped titanium dioxide powder
NOAA	National oceanic and atmospheric administration
NRs	Nanorods
PCE	power conversion efficiency
PEI	Polyethyleneimine
P-TiO_2	Popcorn-like titanium dioxide
PV	Photovoltaic
PVA/TiO_2	Polyvinyl alcohol/titanium dioxide
R	Reduced redox species
R^+	Oxidized redox species
RGO	Reduced graphene oxide
RSM/CCD	Response surface methodology with central composite design
SnO_2	Tin oxide
TCMS	Titanium dioxide core-shell microspheres nanostructures
TCO	Transparent conductive oxides
TDIP	Titanium diisopropoxide
THNR	Titanium dioxide hierarchical nanorods
Ti^{4+}	Titanium (IV)
$TiCl_3$	Titanium trichloride
$TiCl_4$	Titanium tetrachloride
TiO_2	Titanium dioxide
TiO_2-GQD	Titanium dioxide decorated by graphene quantum dot
TMMS	Titanium dioxide smooth microspheres surface
TMSR	Titanium dioxide rough microspheres surface

TNA	Titanium dioxide nanotube arrays
TNNW	Titanium dioxide nanowires with nanoscale whiskers
TNW	Titanium dioxide nanowires
TTIP	Titanium tetraisopropoxide
TW	Terawatts
USA	United State America
WER2-O	Titanium dioxide nanocrystalline polygons with rods
W-TiO_2	Worm-like titanium dioxide
WWF	World wide fund
XRD	X-ray diffraction
Yb	Ytterbium
$YbF_3:Eu^{3+}$	Europium ion doped ytterbium fluoride
ZnO	Zinc oxide

CHAPTER 1

INTRODUCTION

1.1 Background of study

In the last few decades, the demand for energy supply increases rapidly as the population around the world keep increasing. According to the International Energy Agency (IEA), the demand for energy is expected to increase by 27% or 3743 million tons of oil equivalent, globally from 2017 to 2040. The problem arises because the mainstream energy supply still depends on non-renewable energy such as petroleum, natural gas and charcoal. This type of energy is limited and causes pollution. One of the main concerns regarding the pollution caused by the use of non-renewable energy is global warming, where carbon dioxide (CO_2) emission is the main cause of this problem. The global CO_2 emission has increased significantly from 2 billion tons per year in 1900 to over 36 billion tons per year in 2015, increasing the average global temperature (Le Quéré *et al.*, 2018). According to National Oceanic and Atmospheric Administration (NOAA), the earth experienced its second warmest year on the record in 2019 (0.95 °C) which is only 0.04 °C less than the earth's highest temperature rise in 2016. According to the World Wide Fund (WWF), global warming will cause the species extinction, coastal erosion, coral bleaching, oceans acidifying and extreme weather event. Besides, global warming will lead to the rise in sea level due to the melting of glaciers and ice caps that increase the volume of water in the ocean. As a result, low-lying island and coastal cities will be drowned and disappeared.

Therefore, a lot of efforts have been given to counter the energy and pollution crisis that occurs throughout the world by shifting the source of energy supply from non-renewable towards green renewable energy sources. The International Renewable Energy Agency (IRENA) reported that global renewable energy continues to undergo a positive growth by additions of 171 gigawatts (GW) power in 2018. The increase in the production of power is mainly boosted by solar and wind energy. Other renewable energies such as bioenergy, geothermal, hydropower and ocean also contribute to the positive growth in the development of renewable energy worldwide. Among renewable energies, solar energy is the most promising renewable energy resource due to the unlimited supply of sunlight, facile fabrication process and high power generation efficiency (Shaikh *et al.*, 2017). Solar cells or photovoltaic (PV) cells produce electricity by harnessing the energy from the photon of sunlight. The produced energy is called solar energy and the discovery of the PV effect has begun as early in 1839 by Alexandre Becquerel. Solar energy is classified into four different generations. The first generation of solar cells is the most common solar cell available in the industry which is made of single and multi-crystalline silicon. However, due to high fabrication costs, the second generation of solar cells was introduced which is made of thin-film solar cells. The thickness of the solar cells of this generation was reduced to nanometers in order to reduce the fabrication cost. In the meantime, the third generation such as dye-sensitized solar cells (DSSCs), quantum dots solar cells, organic solar cells and perovskite solar cells have gathered numerous attention due to the simple fabrication process and high power conversion efficiency (PCE). The emerging solar cells or fourth-generation solar cells consist of a combination of inorganic and organic materials to boost the PCE and lower the cost of the solar cells (Jayawardena *et al.*, 2013).

1.2 Problem statements

DSSCs are the third-generation solar cell that capable of converting sunlight into electrical energy where the source of electrons comes from the dye compared with the conventional solar cell where the main source of the electrons comes from the semiconductor (Chander *et al.*, 2015). Compared to other types of solar cells, DSSCs have attracted numerous attention due to their low fabrication cost, simple experimental design and moderate PCE. A complete DSSC consists of four main components which are photoanode, counter electrode, dye and electrolyte. Among them, photoanode plays a crucial role in the production of high PCE. Titanium dioxide (TiO_2) is the most common material used as a photoanode in DSSCs due to its high surface area and high porosity which is effective for the dye adsorption process (Kim *et al.*, 2012b). However, TiO_2 as the photoanodes in DSSC has faced a lot of drawbacks such as a small range of light scattering, high recombination effect and low charge transport ability that reduces its PCE.

The recombination effect is the process where the amount of photocurrent and voltage produced is reduced due to the unnecessary recombination. There are three possible routes of recombination in DSSC which are (i) the recombination between electrons of excited dyes and hole of dyes, (ii) the recombination between electrons of TiO_2 with the oxidized redox species and (iii) the recombination between the electrons of transparent conductive oxides (TCO) substrate and the redox electrolyte (Gregg *et al.*, 2001). The first and second recombination routes can be prevented using suitable types of dyes and suitable types of electrolytes, respectively while the third route of recombination can be overcome by introducing a compact layer in between the porous TiO_2 nanoparticles and TCO substrates. The compact layer must be thin, compact and conductive to reduce the recombination effect and facilitates the electron-hole regeneration process. The compact layer is mostly made of metal oxides or carbon-based materials because both materials are conductive and capable to form a thin and compact film. However, metal oxides are more preferable compared to carbon-based materials because the former can sustain high heat treatment during the preparation of photoanode. In this study, TiO_2 compact layer was successfully prepared and optimized using a heat treatment assisted electrospinning and response surface methodology with central composite design (RSM/CCD), respectively.

Furthermore, TiO_2 as the photoanode also suffers from a small range of light scattering and low charge transport and this problem can be overcome by introducing a light scattering layer (LSL) on top of the photoanodes. The LSL helps to traps more sunlight, resulting in more excitation of electrons and producing more photocurrent and voltage that leads to a higher PCE. The LSL must be conductive and larger (>250 nm) compared to the porous TiO_2 nanoparticles (10-30 nm) to enhance the light scattering effect. The large LSL is important to reflect the incident sunlight back to the sensitized TiO_2 film, resulting to increase in the excitation of electrons and produce more photocurrent. In this study, two types of LSL were introduced i.e. polyvinyl alcohol/titanium dioxide (PVA/TiO_2) nanofibers and titanium dioxide decorated by graphene quantum dot (TiO_2-GQD) LSL.

In addition, typical glass substrate based DSSC devices are rigid and inflexible, therefore the application is limited to flat surfaces such as rooftop and window. In order to overcome this problem, a fully flexible DSSC device made of TiO_2 nanoparticles with TiO_2-GQD LSL on flexible plastic substrate indium doped tin oxide/polyethylene naphthalate (ITO/PEN) were introduced.

1.3 Objectives of research

The objectives of this research are:

1. To prepare and optimize the TiO_2 compact layer using heat treatment assisted electrospinning and response surface methodology.
2. To evaluate the effect of concentration of PVA and volume of titanium tetraisopropoxide on the DSSC performance of TiO_2-PVA nanofibers as a light scatterer.
3. To optimize and evaluate the DSSC performance of TiO_2 decorated by GQD as a light scattering layer.
4. To develop and assess a fully flexible DSSC made of TiO_2-GQD as a light scatterer.

1.4 Scope of study

This study focused on the preparation and optimization of the compact layer and LSL to enhance DSSC performance. The TiO_2 compact layer was prepared by heat treatment assisted electrospinning to overcome the recombination effect. The preparation of the TiO_2 compact layer was optimized using response surface methodology with central composite design (RSM/CCD). The first LSL was made of PVA/TiO_2 nanofibers that were successfully prepared via electrospinning and optimized using RSM/CCD, respectively. The second LSL i.e. TiO_2-GQD was prepared via electrodeposition of TiO_2 and drop-casted of GQD. The preparation of TiO_2-GQD LSL was optimized using RSM/CCD. The GQD was introduced as an LSL due to unique photoluminescence properties that can broaden the light-harvesting range from the ultraviolet range to near infra-red range. A fully flexible DSSC device also was introduced as to widen the application of DSSCs due to its attractive traits such as flexible, lightweight, thin and capable to generate moderate PCE.

1.5 Organization of chapter

This thesis consists of 9 chapters and constructed as follows. Chapter 1 describes the background of the study, problem statements, objectives of research and scope of the study. Chapter 2 contains a comprehensive review of photoanodes for DSSCs where a detailed explanation of the compact layer and LSL is discussed. Chapter 3 discusses the optimization of the PVA/TiO_2 compact layer using RSM/CCD while, Chapter 4 elaborates on the characterization and DSSC performances of the PVA/TiO_2 compact layer. Chapters 5 elaborates the preparation and optimization of PVA/TiO_2 nanofibers as an LSL using electrospinning and RSM/CCD, respectively. The DSSC performances of PVA/TiO_2 nanofibers are discussed in Chapter 6. The optimization (RSM/CCD) and DSSC performance of TiO_2 decorated by GQD as a light scatterer are studied in Chapters 7 and 8 respectively. Chapter 9 reports the preparation and characterization of fully flexible DSSC consisting of TiO_2 decorated by GQD as an LSL. The last chapter describes the conclusions and recommendations to improve the DSSC performances.

REFERENCES

Abdullah, M. H. and Rusop, M. (2013) Multifunctional graded index TiO_2 compact layer for performance enhancement in dye sensitized solar cell. *Applied Surface Science.* 284**.** 278-284.

Akilimali, R., Selopal, G. S., Benetti, D., Serrano-Esparza, I., Algarabel, P. A., De Teresa, J. M., Wang, Z. M., Stansfield, B., Zhao, H. and Rosei, F. (2018) Hybrid TiO_2-Graphene nanoribbon photoanodes to improve the photoconversion efficiency of dye sensitized solar cells. *Journal of Power Sources.* 396**.** 566-573.

Ali, T., Tripathi, P., Ameer, A., Waseem, R., Arham, S. A., Ateeq, A. and Muneer, M. (2017) Photocatalytic performance of Fe-doped TiO_2 nanoparticles under visible-light irradiation. *Materials Research Express.* 4**.** 015022-015034.

Apriani, T., Arsyad, W. S., Wulandari, P. and Hidayat, R. (2016) Investigation on the influences of layer structure and nanoporosity of light scattering TiO_2 layer in DSSC. *Journal of Physics: Conference Series.* 739**.** 012134.

Arabatzis, I. M., Stergiopoulos, T., Bernard, M. C., Labou, D., Neophytides, S. G. and Falaras, P. (2003) Silver-modified titanium dioxide thin films for efficient photodegradation of methyl orange. *Applied Catalysis B: Environmental.* 42**.** 187-201.

Arifin, Z., Suyitno, S., Hadi, S. and Sutanto, B. (2018) Improved performance of dye-sensitized solar cells with TiO_2 nanoparticles/Zn-doped TiO_2 hollow fiber photoanodes. *Energies.* 11.

Azman, N. H. N., Lim, H. N., Mamat, M. S. and Sulaiman, Y. (2018) Synergistic enhancement of ternary poly(3,4-ethylenedioxythiophene)/graphene oxide/manganese oxide composite as a symmetrical electrode for supercapacitors. *Energies.* 11**.** 1510.

Badr, M. H., El-Kemary, M., Ali, F. A. and Ghazy, R. (2019) Effect of $TiCl_4$-based TiO_2 compact and blocking layers on efficiency of dye-sensitized solar cells. *Journal of the Chinese Chemical Society.* 66**.** 459-466.

Baiju, K. G., Murali, B., Subba Rao, R., Jayanarayanan, K. and Kumaresan, D. (2020) Heat sink assisted elevated temperature sintering process of TiO_2 on polymer substrates for producing high performance flexible dye-sensitized solar cells. *Chemical Engineering and Processing - Process Intensification.* 149**.** 107817.

Balraju, P., Kumar, M., Roy, M. S. and Sharma, G. D. (2009) Dye sensitized solar cells (DSSCs) based on modified iron phthalocyanine nanostructured TiO_2 electrode and PEDOT:PSS counter electrode. *Synthetic Metals.* 159**.** 1325-1331.

Balu, M., Baiju, K. G., Subramaniam, M. R. and Kumaresan, D. (2019) Bi-layer photoanodes with superior charge collection ability and diffusion length of sub-layer nanostructures for the fabrication of high efficiency dye-sensitized solar cells. *Electrochimica Acta.* 319**.** 339-348.

Banik, A., Ansari, M. S. and Qureshi, M. (2019) Superior light harnessing and charge injection kinetics utilizing mirror-like nano cuboidal ceria coupled with reduced graphene oxide in zinc oxide nanoparticle based photovoltaics. *Solar Energy.* 185**.** 89-99.

Basri, N. a. F., Mustafa, M. N. and Sulaiman, Y. (2019) Facile fabrication of PVA nanofiber coated with PEDOT as a counter electrode for dye-sensitized solar cell. *Journal of Materials Science: Materials in Electronics.* 1-7.

Behrens, A. M., Casey, B. J., Sikorski, M. J., Wu, K. L., Tutak, W., Sandler, A. D. and Kofinas, P. (2014) In Situ Deposition of PLGA Nanofibers via Solution Blow Spinning. *ACS Macro Letters.* 3**.** 249-254.

Bi, S.-Q., Zheng, Y.-Z., Ding, H.-Y., Tao, X. and Chen, J.-F. (2013) A gel-state dye-sensitized hierarchically structured ZnO solar cell: Retention of power conversion efficiency and durability. *Electrochimica Acta.* 114**.** 700-705.

Caglar, M., Ilican, S., Caglar, Y. and Yakuphanoglu, F. (2009) Electrical conductivity and optical properties of ZnO nanostructured thin film. *Applied Surface Science.* 255**.** 4491-4496.

Cameron, P. J. and Peter, L. M. (2003) Characterization of titanium dioxide blocking layers in dye-sensitized nanocrystalline solar cells. *The Journal of Physical Chemistry B.* 107**.** 14394-14400.

Cameron, P. J. and Peter, L. M. (2005) How does back-reaction at the conducting glass substrate influence the dynamic photovoltage response of nanocrystalline dye-sensitized solar cells? *The Journal of Physical Chemistry B.* 109**.** 7392-7398.

Cao, F., Oskam, G., J. Meyer, G. and Searson, P. (1996) Electron transport in porous nanocrystalline TiO_2 photoelectrochemical cells. *Journal of Physical Chemistry.* 100**.** 17021-17027.

Chander, A. H., Krishna, M. and Srikanth, Y. (2015) Comparison of different types of solar cells–a review. *Journal of Electrical Engineering.* 10**.** 151-154.

Chang, H.-C., Twu, M.-J., Hsu, C.-Y., Hsu, R.-Q. and Kuo, C.-G. (2014) Improved performance for dye-sensitized solar cells using a compact TiO_2 layer grown by sputtering. *International Journal of Photoenergy.* 2014**.** 1-8.

Chang, W.-C., Tang, B.-H., Lu, Y.-W., Yu, W.-C., Lin, L.-Y. and Wu, R.-J. (2016) Incorporating hydrangea-like titanium dioxide light scatterer with high dye-loading on the photoanode for dye-sensitized solar cells. *Journal of Power Sources.* 319**.** 131-138.

Chen, B., Doucette, G. and Priya, S. (2013) Improved performance of flexible dye-sensitized solar cells based on hierarchical TiO2 nanostructures with high surface area. *RSC Advances.* 3**.** 24560-24566.

Chen, C., Luo, F., Li, Y., Sewvandi, G. A. and Feng, Q. (2017) Single-crystalline anatase TiO_2 nanoleaf: Simple topochemical synthesis and light-scattering effect for dye-sensitized solar cells. *Materials Letters.* 196**.** 50-53.

Chen, D.-Y., Kao, J.-Y., Hsu, C.-Y. and Tsai, C.-H. (2016) The effect of AZO and compact TiO_2 films on the performance of dye-sensitized solar cells. *Journal of Electroanalytical Chemistry.* 766**.** 1-7.

Chen, H., Wei, Z., Yan, K., Yi, Y., Wang, J. and Yang, S. (2014) Liquid phase deposition of TiO_2 nanolayer affords $CH_3NH_3PbI_3$/nanocarbon solar cells with high open-circuit voltage. *Faraday Discussions.* 176**.** 271-286.

Chen, K.-W., Chen, L.-S. and Chen, C.-M. (2019a) Post-treatment of Nb_2O_5 compact layer in dye-sensitized solar cells for low-level lighting applications. *Journal of Materials Science: Materials in Electronics.* 30**.** 15105-15115.

Chen, T., Hu, W., Song, J., Guai, G. H. and Li, C. M. (2012) Interface functionalization of photoelectrodes with graphene for high performance dye-sensitized solar cells. *Advanced Functional Materials.* 22. 5245-5250.

Chen, X., Du, Q., Yang, W., Liu, W., Miao, Z. and Yang, P. (2018) A double-layered photoanode made of ZnO/TiO_2 composite nanoflowers and TiO_2 nanorods for high efficiency dye-sensitized solar cells. *Journal of Solid State Electrochemistry.* 22. 685-691.

Chen, Y.-Z., Wu, R.-J., Lin, L.-Y. and Chang, W.-C. (2019b) Novel synthesis of popcorn-like TiO_2 light scatterers using a facile solution method for efficient dye-sensitized solar cells. *Journal of Power Sources.* 413. 384-390.

Chinnusamy, S., Kaur, R., Bokare, A. and Erogbogbo, F. (2018) Incorporation of graphene quantum dots to enhance photocatalytic properties of anatase TiO_2. *MRS Communications.* 8. 137-144.

Cho, T. Y., Yoon, S.-G., Sekhon, S., Kang, M. and Han, C.-H. (2011) The effect of a sol-gel formed TiO_2 blocking layer on the efficiency of dye-sensitized solar cells. *Bulletin- Korean Chemical Society.* 32. 3629-3633.

Chou, J., Lin, Y., Liao, Y., Lai, C., Chu, C., You, P. and Nien, Y. (2016) Photovoltaic performance analysis of dye-sensitized solar cell with ZnO compact layer and TiO_2/graphene oxide composite photoanode. *IEEE Journal of the Electron Devices Society.* 4. 402-409.

Chou, J., Lu, C., Liao, Y., Lai, C., Nien, Y., Kuo, C. and Ko, C. (2019) Fabrication and electrochemical impedance analysis of dye-sensitized solar cells with titanium dioxide compact layer and graphene oxide dye absorption layer. *IEEE Transactions on Nanotechnology.* 18. 461-466.

Chougala, L., S. Yatnatti, M., K. Linganagoudar, R., Kamble, R. and S. Kadadevarmath, J. (2017) A simple approach on synthesis of Tio_2 nanoparticles and its application in dye sensitized solar cells. *Journal of Nano- and Electronic Physics.* 9. 04005-1.

Cui, Y., He, X., Zhu, M. and Li, X. (2017) Preparation of anatase TiO_2 microspheres with high exposure (001) facets as the light-scattering layer for improving performance of dye-sensitized solar cells. *Journal of Alloys and Compounds.* 694. 568-573.

Cui, Y., Wang, W., Li, N., Ding, R. and Hong, K. (2019) Hetero-seed meditated method to synthesize ZnO/TiO_2 multipod nanostructures with ultra-high yield for dye-sensitized solar cells. *Journal of Alloys and Compounds.* 805. 868-872.

Das, P., Mondal, B. and Mukherjee, K. (2018) Improved efficiency of ZnO hierarchical particle based dye sensitized solar cell by incorporating thin passivation layer in photo-anode. *Applied Physics A.* 124. 80.

De Jongh, P. E. and Vanmaekelbergh, D. (1997) Investigation of the electronic transport properties of nanocrystalline particulate TiO_2 electrodes by intensity-modulated photocurrent spectroscopy. *The Journal of Physical Chemistry B.* 101. 2716-2722.

Deepak, T. G., Anjusree, G. S., Thomas, S., Arun, T. A., Nair, S. V. and Sreekumaran Nair, A. (2014) A review on materials for light scattering in dye-sensitized solar cells. *RSC Advances.* 4. 17615-17638.

Dinari, M., Momeni, M. M. and Goudarzirad, M. (2016) Dye-sensitized solar cells based on nanocomposite of polyaniline/graphene quantum dots. *Journal of Materials Science.* 51. 2964-2971.

Dong, Z., Kennedy, S. J. and Wu, Y. (2011) Electrospinning materials for energy-related applications and devices. *Journal of Power Sources.* 196**.** 4886-4904.

Dongshe, Z., Yoshida, T., Furuta, K. and Minoura, H. (2004) Hydrothermal preparation of porous nano-crystalline TiO_2 electrodes for flexible solar cells. *Journal of Photochemistry and Photobiology A: Chemistry.* 164**.** 159–166.

Fan, K., Yu, J. and Ho, W. (2017) Improving photoanodes to obtain highly efficient dye-sensitized solar cells: a brief review. *Materials Horizons.* 4**.** 319-344.

Fang, X., Li, M., Guo, K., Li, J., Pan, M., Bai, L., Luoshan, M. and Zhao, X. (2014) Graphene quantum dots optimization of dye-sensitized solar cells. *Electrochimica Acta.* 137**.** 634-638.

Fernández-Acosta, R., Peláez-Abellán, E., Correa, J. R. and Jáuregui-Haza, U. (2016) Nanostructured TiO_2 obtained by electrolysis and its application in the remediation of water polluted with paracetamol. *Int J Chem Mater Environ Res.* 3**.** 20-28.

Fischer, K., Gawel, A., Rosen, D., Krause, M., Latif, A., Griebel, J., Prager, A. and Schulze, A. (2017) Low-temperature synthesis of anatase/rutile/brookite TiO_2 nanoparticles on a polymer membrane for photocatalysis. *Catalysts.* 7**.** 209.

Gan, W. Y., Lam, S. W., Chiang, K., Amal, R., Zhao, H. and Brungs, M. P. (2007) Novel TiO_2 thin film with non-UV activated superwetting and antifogging behaviours. *Journal of Materials Chemistry.* 17**.** 952-954.

García-Gómez, C., Drogui, P., Zaviska, F., Seyhi, B., Gortarés-Moroyoqui, P., Buelna, G., Neira-Sáenz, C., Estrada-Alvarado, M. and Ulloa-Mercado, R. (2014) Experimental design methodology applied to electrochemical oxidation of carbamazepine using Ti/PbO_2 and Ti/BDD electrodes. *Journal of Electroanalytical Chemistry.* 732**.** 1-10.

Ghann, W., Kang, H., Sheikh, T., Yadav, S., Chavez-Gil, T., Nesbitt, F. and Uddin, J. (2017) Fabrication, optimization and characterization of natural dye sensitized solar cell. *Scientific Reports.* 7**.** 41470.

Ghayoor, R., Keshavarz, A. and Soltani Rad, M. N. (2019) Facile preparation of TiO_2 nanoparticles decorated by the graphene for enhancement of dye-sensitized solar cell performance. *Journal of Materials Research.* 34**.** 2014-2023.

Gong, J., Qiao, H., Sigdel, S., Elbohy, H., Adhikari, N., Zhou, Z., Sumathy, K., Wei, Q. and Qiao, Q. (2015) Characteristics of SnO_2 nanofiber/TiO_2 nanoparticle composite for dye-sensitized solar cells. *AIP Advances.* 5**.** 067134.

Gong, J., Sumathy, K., Qiao, Q. and Zhou, Z. (2017) Review on dye-sensitized solar cells (DSSCs): Advanced techniques and research trends. *Renewable and Sustainable Energy Reviews.* 68**.** 234-246.

Grätzel, M. (2000) Perspectives for dye-sensitized nanocrystalline solar cells. *Progress in photovoltaics: research and applications.* 8**.** 171-185.

Grätzel, M. (2003) Dye-sensitized solar cells. *Journal of photochemistry and photobiology C: Photochemistry Reviews.* 4**.** 145-153.

Grätzel, M. (2004) Conversion of sunlight to electric power by nanocrystalline dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry.* 164**.** 3-14.

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.
Gregg, B. A., Pichot, F., Ferrere, S. and Fields, C. L. (2001) Interfacial recombination processes in dye-sensitized solar cells and methods to passivate the interfaces. *The Journal of Physical Chemistry B.* 105**.** 1422-1429.
Guan, Y., Song, L., Zhou, Y., Yin, X., Xie, X. and Xiong, J. (2017) Enhanced light harvesting of dye-sensitized solar cells with TiO_2 microspheres as light scattering layer. *Applied Physics A.* 123**.** 193.
Guo, Y., Zou, T., Cheng, Q., Jiao, B. and Zhang, X. (2019a) Towards improvement of photovoltaic performance of aqueous dye-sensitized solar cells by tungsten-doped mesoporous nanobeads TiO_2 working electrode. *Journal of Wuhan University of Technology-Mater. Sci. Ed.* 34**.** 17-22.
Guo, Z. L., Zhuang, J., Ma, Z., Xia, H. R., Wen, Q. X., Luo, X. Y. and Wen, X. (2019b) Enhanced electron extraction using ZnO/ZnO-SnO_2 solid double-layer photoanode thin films for efficient dye sensitized solar cells. *Thin Solid Films.* 684**.** 1-8.
Hafizah, N. and Sopyan, I. (2009) Nanosized TiO_2 photocatalyst powder via sol-gel method: effect of hydrolysis degree on powder properties. *International Journal of Photoenergy.* 2009**.** 8.
Hagfeldt, A., Boschloo, G., Sun, L., Kloo, L. and Pettersson, H. (2010) Dye-sensitized solar cells. *Chemical Reviews.* 110**.** 6595-6663.
Haider, S., Al-Zeghayer, Y., Ali, F. a. A., Haider, A., Mahmood, A., Al-Masry, W. A., Imran, M. and Aijaz, M. O. (2013) Highly aligned narrow diameter chitosan electrospun nanofibers. *Journal of Polymer Research.* 20**.** 105.
Hannappel, T., Burfeindt, B., Storck, W. and Willig, F. (1997) Measurement of ultrafast photoinduced electron transfer from chemically anchored Ru-dye molecules into empty electronic states in a colloidal anatase TiO_2 film. *The Journal of Physical Chemistry B.* 101**.** 6799-6802.
Hart, J. N., Menzies, D., Cheng, Y. B., Simon, G. P. and Spiccia, L. (2006) TiO_2 sol-gel blocking layers for dye-sensitized solar cells. *Comptes Rendus Chimie.* 9**.** 622-626.
Hassanzadeh, P., Kharaziha, M., Nikkhah, M., Shin, S. R., Jin, J., He, S., Sun, W., Zhong, C., Dokmeci, M. R., Khademhosseini, A. and Rolandi, M. (2013) Chitin nanofiber micropatterned flexible substrates for tissue engineering. *Journal of Materials Chemistry B.* 1**.** 4217-4224.
Hattori, R. and Goto, H. (2007) Carrier leakage blocking effect of high temperature sputtered TiO2 film on dye-sensitized mesoporous photoelectrode. *Thin Solid Films.* 515**.** 8045-8049.
He, X., Li, X. and Zhu, M. (2016) The application of hollow box TiO_2 as scattering centers in dye-sensitized solar cells. *Journal of Power Sources.* 333**.** 10-16.
He, X., Liu, J., Zhu, M., Guo, Y., Ren, Z. and Li, X. (2017) Preparation of hierarchical rutile TiO_2 microspheres as scattering centers for efficient dye-sensitized solar cells. *Electrochimica Acta.* 255**.** 187-194.
Hirata, N., Lagref, J.-J., Palomares, E. J., Durrant, J. R., Nazeeruddin, M. K., Gratzel, M. and Di Censo, D. (2004) Supramolecular control of charge-

transfer dynamics on dye-sensitized nanocrystalline TiO_2 films. *Chemistry – A European Journal.* 10**.** 595-602.

Ho, P., Bao, L. Q., Ahn, K.-S., Cheruku, R. and Kim, J. H. (2016) P-Type dye-sensitized solar cells: Enhanced performance with a NiO compact blocking layer. *Synthetic Metals.* 217**.** 314-321.

Hu, J.-H., Tong, S.-Q., Yang, Y.-P., Cheng, J.-J., Zhao, L. and Duan, J.-X. (2016) A composite photoanode based on P25/TiO_2 nanotube arrays/flower-like TiO_2 for high-efficiency dye-sensitized solar cells. *Acta Metallurgica Sinica (English Letters).* 29**.** 840-847.

Huang, C.-Y., Chen, P.-H., Wu, Y.-J., Chiang, H.-P., Hwang, J.-S., Lin, P.-T., Lai, K.-Y., Chien, F. S.-S. and Lin, T.-Y. (2017) Enhanced performance of ZnO-based dye-sensitized solar cells using TiO_2/graphene nanocomposite compact layer. *Japanese Journal of Applied Physics.* 56**.** 045201.

Huang, C., Bai, H., Huang, Y., Liu, S., Yen, S. and Tseng, Y. (2012) Synthesis of neutral SiO_2/TiO_2 hydrosol and its application as antireflective self-cleaning thin film. *International Journal of Photoenergy.* 2012**.** 1-8.

Huang, C. H., Chang, K. S. and Hsu, C. Y. (2015) TiO_2 compact layers prepared for high performance dye-sensitized solar cells. *Electrochimica Acta.* 170**.** 256-262.

Huang, J.-J., Chiu, S.-P., Wu, M.-J. and Hsu, C.-F. (2016a) Effect of titanium oxide compact layer in dye-sensitized solar cell prepared by liquid-phase deposition. *Applied Physics A.* 122**.** 971-977.

Huang, J.-J., Ou, S.-L., Hsu, C.-F. and Shen, X.-Q. (2019) The effect of boric acid concentration on the TiO_2 compact layer by liquid-phase deposition for dye-sensitized solar cell. *Applied Surface Science.* 477**.** 7-14.

Huang, J., Her, S.-C., Yang, X. and Zhi, M. (2018) Synthesis and characterization of multi-walled carbon nanotube/graphene nanoplatelet hybrid film for flexible strain sensors. *Nanomaterials.* 8**.** 786.

Huang, S., Song, L., Xiao, Z., Hu, Y., Peng, M., Li, J., Zheng, X., Wu, B. and Yuan, C. (2016b) Graphene quantum dot-decorated mesoporous silica nanoparticles for high aspirin loading capacity and its pH-triggered release. *Analytical Methods.* 8**.** 2561-2567.

Jayawardena, K. D. G. I., Rozanski, L. J., Mills, C. A., Beliatis, M. J., Nismy, N. A. and Silva, S. R. P. (2013) 'Inorganics-in-Organics': recent developments and outlook for 4G polymer solar cells. *Nanoscale.* 5**.** 8411-8427.

Jeng, M.-J., Wung, Y.-L., Chang, L.-B. and Chow, L. (2013) Particle size effects of TiO_2 layers on the solar efficiency of dye-sensitized solar cells. *International Journal of Photoenergy.* 2013**.** 9.

Ji, D., Fan, L., Li, L., Peng, S., Yu, D., Song, J., Ramakrishna, S. and Guo, S. (2019) Atomically transition metals on self-supported porous carbon flake arrays as binder-free air cathode for wearable zinc−air batteries. *Advanced Materials.* 31**.** 1808267.

Ji, D., Peng, S., Safanama, D., Yu, H., Li, L., Yang, G., Qin, X., Srinivasan, M., Adams, S. and Ramakrishna, S. (2017) Design of 3-dimensional hierarchical architectures of carbon and highly active transition metals (Fe, Co, Ni) as bifunctional oxygen catalysts for hybrid lithium–air batteries. *Chemistry of Materials.* 29**.** 1665-1675.

Jiu, J., Isoda, S., Wang, F. and Adachi, M. (2006) Dye-sensitized solar cells based on a single-crystalline TiO_2 nanorod film. *The Journal of Physical Chemistry B.* 110**.** 2087-2092.

Jiwei Ma, M., Li, W. and Dambournet, D. (2017) 22 - Solution-based synthesis of nano-sized TiO_2 anatase in fluorinating media. IN GROULT, H., LEROUX, F. R. & TRESSAUD, A. (Eds.) *Modern synthesis processes and reactivity of fluorinated compounds.* Elsevier.

Joshi, P., Zhang, L., Davoux, D., Zhu, Z., Galipeau, D., Fong, H. and Qiao, Q. (2010) Composite of TiO_2 nanofibers and nanoparticles for dye-sensitized solar cells with significantly improved efficiency. *Energy & Environmental Science.* 3**.** 1507-1510.

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.

Kaidashev, E. M., Lorenz, M., Von Wenckstern, H., Rahm, A., Semmelhack, H. C., Han, K. H., Benndorf, G., Bundesmann, C., Hochmuth, H. and Grundmann, M. (2003) High electron mobility of epitaxial ZnO thin films on c-plane sapphire grown by multistep pulsed-laser deposition. *Applied Physics Letters.* 82**.** 3901-3903.

Kakiage, K., Aoyama, Y., Yano, T., Oya, K., Fujisawa, J.-I. and Hanaya, M. (2015) Highly-efficient dye-sensitized solar cells with collaborative sensitization by silyl-anchor and carboxy-anchor dyes. *Chemical Communications.* 51**.** 15894-15897.

Kavan, L., Steier, L. and Grätzel, M. (2017) Ultrathin buffer layers of SnO_2 by atomic layer deposition: perfect blocking function and thermal stability. *The Journal of Physical Chemistry C.* 121**.** 342-350.

Kenry and Lim, C. T. (2017) Nanofiber technology: current status and emerging developments. *Progress in Polymer Science.* 70**.** 1-17.

Kharazmi, A., Faraji, N., Mat Hussin, R., Saion, E., Mat Yunus, W. M. and Behzad, K. (2015) *Structural, optical, opto-thermal and thermal properties of ZnS–PVA nanofluids synthesized through a radiolytic approach.*

Khedr, G. E., Abdallah, T., Morsi, R. E. and Talaat, H. (2019) Enhanced photovoltaic parameters of titania/graphene nanocomposites based dye sensitized solar cells. *Journal of Physics: Conference Series.* 1253**.** 012030.

Kim, D. H., Lee, S., Park, J. H., Noh, J. H., Park, I. J., Seong, W. M. and Hong, K. S. (2012a) Transmittance optimized nb-doped TiO_2/Sn-doped In_2O_3 multilayered photoelectrodes for dye-sensitized solar cells. *Solar Energy Materials and Solar Cells.* 96**.** 276-280.

Kim, D. H., Park, M. S., Kim, D. J., Cho, H. H. and Kim, J. H. (2017) Solid polymer electrolyte dye-sensitized solar cells with organized mesoporous TiO_2 interfacial layer templated by poly(vinyl alcohol)–poly(methyl methacrylate) comb copolymer. *Solid State Ionics.* 300**.** 195-204.

Kim, H.-B., Park, D.-W., Jeun, J.-P., Oh, S.-H., Nho, Y.-C. and Kang, P.-H. (2012b) Effects of electron beam irradiation on the photoelectrochemical properties of TiO_2 film for DSSCs. *Radiation Physics and Chemistry.* 81**.** 954-957.

Kim, J., Lee, B., Kim, Y. J. and Hwang, S. W. (2019) Enhancement of dye-sensitized solar cells efficiency using graphene quantum dots as photoanode. *Bulletin of the Korean Chemical Society.* 40**.** 56-61.
Kim, S. G., Ju, M. J., Choi, I. T., Choi, W. S., Choi, H.-J., Baek, J.-B. and Kim, H. K. (2013) Nb-doped TiO_2 nanoparticles for organic dye-sensitized solar cells. *RSC Advances.* 3**.** 16380-16386.
Kim, S. R., Parvez, M. K. and Chhowalla, M. (2009) UV-reduction of graphene oxide and its application as an interfacial layer to reduce the back-transport reactions in dye-sensitized solar cells. *Chemical Physics Letters.* 483**.** 124-127.
Kishore Kumar, D., Hsu, M.-H., Ivaturi, A., Chen, B., Bennett, N. and Upadhyaya, H. M. (2019) Optimizing room temperature binder free TiO_2 paste for high efficiency flexible polymer dye sensitized solar cells. *Flexible and Printed Electronics.* 4**.** 015007.
Kokubo, H., Ding, B., Naka, T., Tsuchihira, H. and Shiratori, S. (2007) Multi-core cable-like TiO_2 nanofibrous membranes for dye-sensitized solar cells. *Nanotechnology.* 18**.** 165604.
Koo, B.-R., Oh, D.-H. and Ahn, H.-J. (2018) Influence of Nb-doped TiO_2 blocking layers as a cascading band structure for enhanced photovoltaic properties. *Applied Surface Science.* 433**.** 27-34.
Koyama, Y., Miki, T., Wang, X.-F. and Nagae, H. (2009) Dye-sensitized solar cells based on the principles and materials of photosynthesis: Mechanisms of suppression and enhancement of photocurrent and conversion efficiency. *International Journal of Molecular Sciences.* 10**.** 4575-4622.
Krishnamurthy, K. N., Sridhara, S. N. and Ananda Kumar, C. S. (2020) Optimization and kinetic study of biodiesel production from Hydnocarpus wightiana oil and dairy waste scum using snail shell CaO nano catalyst. *Renewable Energy.* 146**.** 280-296.
Krumpmann, A., Dervaux, J., Derue, L., Douhéret, O., Lazzaroni, R., Snyders, R. and Decroly, A. (2017) Influence of a sputtered compact TiO_2 layer on the properties of TiO_2 nanotube photoanodes for solid-state DSSCs. *Materials & Design.* 120**.** 298-306.
Kumar, D. K., Suazo-Davila, D., García-Torres, D., Cook, N. P., Ivaturi, A., Hsu, M.-H., Martí, A. A., Cabrera, C. R., Chen, B., Bennett, N. and Upadhyaya, H. M. (2019a) Low-temperature titania-graphene quantum dots paste for flexible dye-sensitised solar cell applications. *Electrochimica Acta.* 305**.** 278-284.
Kumar, K. A., Subalakshmi, K. and Senthilselvan, J. (2019b) Effect of co-sensitization in solar exfoliated TiO_2 functionalized rGO photoanode for dye-sensitized solar cell applications. *Materials Science in Semiconductor Processing.* 96**.** 104-115.
Kumar, S., Ojha, A., Ahmed, B., Kumar, A., Das, J. and Materny, A. (2017) Tunable (violet to green) emission by high-yield graphene quantum dots and exploiting its unique properties towards sun-light-driven photocatalysis and supercapacitor electrode materials. *Materials Today Communications.* 11.
Kumari, M. G. C. M., Perera, C. S., Dassanayake, B. S., Dissanayake, M. a. K. L. and Senadeera, G. K. R. (2019) Highly efficient plasmonic dye-sensitized solar cells with silver nanowires and TiO_2 nanofibres

incorporated multi-layered photoanode. *Electrochimica Acta.* 298**.** 330-338.
Lai, F.-I., Yang, J.-F., Hsu, Y.-C. and Kuo, S.-Y. (2019a) Omnidirectional light-harvesting enhancement of dye-sensitized solar cells with ZnO nanorods. *International Journal of Energy Research.* 43**.** 3413-3420.
Lai, F.-I., Yang, J.-F., Hsu, Y.-C. and Kuo, S.-Y. (2019b) Omnidirectional light harvesting enhancement of dye-sensitized solar cells decorated with two-dimensional ZnO nanoflowers. *Journal of Alloys and Compounds.* 152287.
Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P. A., Korsbakken, J. I., Peters, G. P., Canadell, J. G., Arneth, A., Arora, V. K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L. P., Ciais, P., Doney, S. C., Gkritzalis, T., Goll, D. S., Harris, I., Haverd, V., Hoffman, F. M., Hoppema, M., Houghton, R. A., Hurtt, G., Ilyina, T., Jain, A. K., Johannessen, T., Jones, C. D., Kato, E., Keeling, R. F., Goldewijk, K. K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P. P., Tian, H., Tilbrook, B., Tubiello, F. N., Van Der Laan-Luijkx, I. T., Van Der Werf, G. R., Viovy, N., Walker, A. P., Wiltshire, A. J., Wright, R., Zaehle, S. and Zheng, B. (2018) Global Carbon Budget 2018. *Earth Syst. Sci. Data.* 10**.** 2141-2194.
Lee, J.-J., Rahman, M., Sarker, S., Nath, N. C. D., Ahammad, A. J. S. and Lee, J. K. (2011) Metal oxides and their composites for dye-sensitized solar cells. *Advances in Composite Materials for Medicine and Nanotechnology.* 181-201.
Lee, J. K. Y., Chen, N., Peng, S., Li, L., Tian, L., Thakor, N. and Ramakrishna, S. (2018) Polymer-based composites by electrospinning: Preparation & functionalization with nanocarbons. *Progress in Polymer Science.* 86**.** 40-84.
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, N. K. (2018) Statistical Optimization of Medium and Fermentation Conditions of Recombinant Pichia pastoris for the Production of Xylanase. *Biotechnology and Bioprocess Engineering.* 23**.** 55-63.
Lellig, P., Niedermeier, M. A., Rawolle, M., Meister, M., Laquai, F., Müller-Buschbaum, P. and Gutmann, J. S. (2012) Comparative study of conventional and hybrid blocking layers for solid-state dye-sensitized solar cells. *Physical Chemistry Chemical Physics.* 14**.** 1607-1613.
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, J., Zhang, H., Wang, W., Qian, Y. and Li, Z. (2016) Improved performance of dye-sensitized solar cell based on TiO_2 photoanode with FTO glass and film both treated by $TiCl_4$. *Physica B: Condensed Matter.* 500**.** 48-52.

Li, L., Xu, C., Zhao, Y., Chen, S. and Ziegler, K. J. (2015) Improving performance via blocking layers in dye-sensitized solar cells based on nanowire photoanodes. *ACS Appl Mater Interfaces.* 7**.** 12824-31.

Lim, S. P., Pandikumar, A., Lim, H. N., Ramaraj, R. and Huang, N. M. (2015) Boosting photovoltaic performance of dye-sensitized solar cells using silver nanoparticle-decorated N,S-Co-doped-TiO_2 photoanode. *Scientific Reports.* 5**.** 11922.

Lin, C.-J., Yu, W.-Y. and Chien, S.-H. (2008) Rough conical-shaped TiO_2-nanotube arrays for flexible backilluminated dye-sensitized solar cells. *Applied Physics Letters.* 93**.** 133107.

Lin, L.-Y., Lee, C.-P., R.Vittal and Ho, K.-C. (2011) Improving the durability of dye-sensitized solar cells through back illumination. *Journal of Power Sources.* 196**.** 1671-1676.

Liu, B. and Aydil, E. S. (2009) Growth of oriented single-crystalline rutile TiO_2 nanorods on transparent conducting substrates for dye-sensitized solar cells. *Journal of the American Chemical Society.* 131**.** 3985-3990.

Liu, I. P., Lin, W.-H., Tseng-Shan, C.-M. and Lee, Y.-L. (2018) Importance of compact blocking layers to the performance of dye-sensitized solar cells under ambient light conditions. *ACS Applied Materials & Interfaces.* 10**.** 38900-38905.

Liu, J., Bai, H., Wang, Y., Liu, Z., Zhang, X. and Sun, D. D. (2010) Self-assembling TiO_2 nanorods on large graphene oxide sheets at a two-phase interface and their anti-recombination in photocatalytic applications. *Advanced Functional Materials.* 20**.** 4175-4181.

Liu, X., Guo, M., Cao, J., Lin, J., Tsang, Y. H., Chen, X. and Huang, H. (2014) Large-diameter titanium dioxide nanotube arrays as a scattering layer for high-efficiency dye-sensitized solar cell. *Nanoscale Research Letters.* 9**.** 362.

Lo, K. S. K. and Leung, W. W. F. (2019) Dye-sensitized solar cells with shear-exfoliated graphene. *Solar Energy.* 180**.** 16-24.

Lu, D., Qin, L., Liu, D., Sun, P., Liu, F. and Lu, G. (2018) High-efficiency dye-sensitized solar cells based on bilayer structured photoanode consisting of carbon nanofiber/TiO_2 composites and Ag@TiO_2 core-shell spheres. *Electrochimica Acta.* 292**.** 180-189.

Maçaira, J., Mesquita, I., Andrade, L. and Mendes, A. (2015) Role of temperature in the recombination reaction on dye-sensitized solar cells. *Physical Chemistry Chemical Physics.* 17**.** 22699-22710.

Madurai Ramakrishnan, V., Sandberg, S., Muthukumarasamy, N., Kvamme, K., Balraju, P., Agilan, S. and Velauthapillai, D. (2019) Microwave-assisted solvothermal synthesis of worms-like TiO_2 nanostructures in submicron regime as light scattering layers for dye-sensitized solar cells. *Materials Letters.* 236**.** 747-751.

Mahalingam, S. and Abdullah, H. (2016) Electron transport study of indium oxide as photoanode in DSSCs: A review. *Renewable and Sustainable Energy Reviews.* 63**.** 245-255.

Mahmoud, M. S., Akhtar, M. S., Mohamed, I. M. A., Hamdan, R., Dakka, Y. A. and Barakat, N. a. M. (2018) Demonstrated photons to electron activity of S-doped TiO_2 nanofibers as photoanode in the DSSC. *Materials Letters.* 225**.** 77-81.

Mardare, D., Baban, C., Gavrila, R., Modreanu, M. and Rusu, G. I. (2002) On the structure, morphology and electrical conductivities of titanium oxide thin films. *Surface Science.* 507-510**.** 468-472.

Mathew, S., Yella, A., Gao, P., Humphry-Baker, R., Curchod, B., Astani, N., Tavernelli, I., Rothlisberger, U., Nazeeruddin, M. and Grätzel, M. (2014) Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers. *Nature chemistry.* 6**.** 242-7.

Mohamed Sharif, N. F., Kadir, M. Z. a. A., Shafie, S., Rashid, S. A., Wan Hasan, W. Z. and Shaban, S. (2019) Charge transport and electron recombination suppression in dye-sensitized solar cells using graphene quantum dots. *Results in Physics.* 13**.** 102171.

Moon, B.-H., Sung, Y.-M. and Han, C.-H. (2013) Titanium oxide films prepared by sputtering, sol gel and dip coating methods for photovoltaic application. *Energy Procedia.* 34**.** 589-596.

Motlak, M., Hamza, A. M., Hammed, M. G. and Barakat, N. a. M. (2019) Cd-doped TiO_2 nanofibers as effective working electrode for the dye sensitized solar cells. *Materials Letters.* 246**.** 206-209.

Musila, N., Munji, M., Simiyu, J., Masika, E. and Nyenge, R. (2018) Effect of TiO_2 compact layer on DSSC performance. *Path of Science.* 4**.** 5001-5008.

Mustafa, M. N., Shafie, S., Wahid, M. H. and Sulaiman, Y. (2019a) Optimization of power conversion efficiency of polyvinyl-alcohol/titanium dioxide as light scattering layer in DSSC using response surface methodology/central composite design. *Results in Physics.* 15**.** 102559.

Mustafa, M. N., Shafie, S., Wahid, M. H. and Sulaiman, Y. (2019b) Optimization of power conversion efficiency of polyvinyl-alcohol/titanium dioxide compact layer using response surface methodology/central composite design. *Solar Energy.* 183**.** 689-696.

Mustafa, M. N., Shafie, S., Wahid, M. H. and Sulaiman, Y. (2020) Preparation of TiO_2 compact layer by heat treatment of electrospun TiO_2 composite for dye-sensitized solar cells. *Thin Solid Films.* 693**.** 137699.

Mustafa, M. N., 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. *Journal of Nanomaterials.* 2017**.** 1-9.

Mustafa, M. N., 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. *Materials & Design.* 136**.** 249-257.

Nair, A. S., Jose, R., Shengyuan, Y. and Ramakrishna, S. (2011) A simple recipe for an efficient TiO_2 nanofiber-based dye-sensitized solar cell. *J Colloid Interface Sci.* 353**.** 39-45.

Navarro-Pardo, F., Benetti, D., Benavides, J., Zhao, H. G., Cloutier, S. G., Castano, V. M., Vomiero, A. and Rosei, F. (2017) Nanofiber-structured TiO_2 nanocrystals as a scattering layer in dye-sensitized solar cells. *ECS Journal of Solid State Science and Technology.* 6**.** N32-N37.

Nemala, S. S., Mokurala, K., Bhargava, P. and Mallick, S. (2018) Titania nanobelts as a scattering layer with Cu_2ZnSnS_4 as a counter electrode for dssc with improved efficiency. *Materials Today: Proceedings.* 5**.** 23351-23357.

Nguyen, D.-T., Kurokawa, Y. and Taguchi, K. (2020) Enhancing dssc photoanode performance by using Ni-doped TiO_2 to fabricate scattering layers. *Journal of Electronic Materials.* 49**.** 2578-2583.

O'brian, N., Grübler, A., Nakicenovic, N., Obersteiner, M., Riahi, K., Schrattenholzer, L. and Toth, F. (2003) Planning for future energy resources. *Science.* 300**.** 581-584.

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.

Ouzzine, M., Maciá-Agulló, J. A., Lillo-Ródenas, M. A., Quijada, C. and Linares-Solano, A. (2014) Synthesis of high surface area TiO_2 nanoparticles by mild acid treatment with HCl or HI for photocatalytic propene oxidation. *Applied Catalysis B: Environmental.* 154-155**.** 285-293.

Parvazian, E., Karimzadeh, F. and Enayati, M. H. (2014) Photovoltaic characterization and electrochemical impedance spectroscopy analysis of dye-sensitized solar cellsbased on composite TiO_2–MWCNT photoelectrodes. *Journal of Electronic Materials.* 43**.** 1450-1459.

Peng, B., Jungmann, G., Jäger, C., Haarer, D., Schmidt, H.-W. and Thelakkat, M. (2004) Systematic investigation of the role of compact TiO_2 layer in solid state dye-sensitized TiO_2 solar cells. *Coordination Chemistry Reviews.* 248**.** 1479-1489.

Peng, S., Jin, G., Li, L., Li, K., Srinivasan, M., Ramakrishna, S. and Chen, J. (2016) Multi-functional electrospun nanofibres for advances in tissue regeneration, energy conversion & storage, and water treatment. *Chemical Society Reviews.* 45**.** 1225-1241.

Pillay, V., Dott, C., Choonara, Y. E., Tyagi, C., Tomar, L., Kumar, P., Du Toit, L. C. and Ndesendo, V. M. (2013) A review of the effect of processing variables on the fabrication of electrospun nanofibers for drug delivery applications. *Journal of Nanomaterials.* 2013.

Prabakar, K., Son, M. K., Ludeman, D. and Kim, H. J. (2010) Visible light enhanced TiO_2 thin film bilayer dye sensitized solar cells. *Thin Solid Films.* 519**.** 894-899.

Prusty, K., Sahu, D. and Swain, S. K. (2017) 19 - Nanocellulose as a template for the production of advanced nanostructured material. IN JAWAID, M., BOUFI, S. & H.P.S, A. K. (Eds.) *Cellulose-Reinforced Nanofibre Composites.* Woodhead Publishing.

Putao, Z., Zhiqiang, H., Yan, W., Yiying, Q., Wenqin, L. and Jinmin, W. (2016) A bi-layer composite film based on TiO_2 hollow spheres, P25 and multi-walled carbon nanotubes for efficient photoanode of dye-sensitized solar cell. *Nano-Micro Letters.* 8.

Pvps (2019) PVPS 2019 snapshot of global PV markets. International Energy Agency.

Rahman, M. Y. A., Samsuri, S. a. M. and Umar, A. A. (2019) TiO_2–$SrTiO_3$ composite photoanode: effect of strontium precursor concentration on the performance of dye-sensitized solar cells. *Applied Physics A.* 125**.** 59.

Raja, R., Govindaraj, M., Antony, M. D., Krishnan, K., Velusamy, E., Sambandam, A., Subbaiah, M. and Rayar, V. W. (2017) Effect of TiO_2/reduced graphene oxide composite thin film as a blocking layer on the efficiency of dye-sensitized solar cells. *Journal of Solid State Electrochemistry.* 21**.** 891-903.

Rajamanickam, G., Narendhiran, S., Muthu, S. P., Mukhopadhyay, S. and Perumalsamy, R. (2017) Hydrothermally derived nanoporous titanium dioxide nanorods/nanoparticles and their influence in dye-sensitized solar cell as a photoanode. *Chemical Physics Letters.* 689**.** 19-25.

Ramar, A., Saraswathi, R., Rajkumar, M. and Chen, S.-M. (2015) Influence of Poly(N-vinylcarbazole) as a Photoanode Component in Enhancing the Performance of a Dye-Sensitized Solar Cell. *Journal of Physical Chemistry C.* 119**.** 23830-23838.

Ramesh, T., Nayak, B., Amirbahman, A., Tripp, C. P. and Mukhopadhyay, S. (2016) Application of ultraviolet light assisted titanium dioxide photocatalysis for food safety: A review. *Innovative Food Science & Emerging Technologies.* 38**.** 105-115.

Ricciardi, R., Auriemma, F., De Rosa, C. and Lauprêtre, F. (2004) X-ray Diffraction Analysis of Poly(vinyl alcohol) Hydrogels, Obtained by Freezing and Thawing Techniques. *Macromolecules.* 37**.** 1921-1927.

Rui, Y., Wang, L., Zhao, J., Wang, H., Li, Y., Zhang, Q. and Xu, J. (2016) Template-free synthesis of hierarchical TiO_2 hollow microspheres as scattering layer for dye-sensitized solar cells. *Applied Surface Science.* 369**.** 170-177.

Salafsky, J. S., Lubberhuizen, W. H., Van Faassen, E. and Schropp, R. E. I. (1998) Charge dynamics following dye photoinjection into a TiO_2 nanocrystalline network. *The Journal of Physical Chemistry B.* 102**.** 766-769.

Senadeera, G. K. R., Weerasinghe, A. M. J. S., Dissanayake, M. a. K. L. and Thotawatthage, C. A. (2018) A five-fold efficiency enhancement in dye sensitized solar cells fabricated with $AlCl_3$ treated, SnO_2 nanoparticle/nanofibre/nanoparticle triple layered photoanode. *Journal of Applied Electrochemistry.* 48**.** 1255-1264.

Sengupta, D., Das, P., Mondal, B. and Mukherjee, K. (2016) Effects of doping, morphology and film-thickness of photo-anode materials for dye sensitized solar cell application – A review. *Renewable and Sustainable Energy Reviews.* 60**.** 356-376.

Seo, H., Son, M.-K., Kim, J.-K., Shin, I., Prabakar, K. and Kim, H.-J. (2011) Method for fabricating the compact layer in dye-sensitized solar cells by titanium sputter deposition and acid-treatments. *Solar Energy Materials and Solar Cells.* 95**.** 340-343.

Seo, H., Son, M. K., Park, S., Kim, H. J. and Shiratani, M. (2012) The blocking effect of charge recombination by sputtered and acid-treated ZnO thin film in dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry.* 248**.** 50-54.

Shaikh, M. R., Shaikh, S., Waghmare, S., Labade, S. and Tekale, A. (2017) A review paper on electricity generation from solar energy. *International Journal for Research in Applied Science and Engineering Technology.* 5**.** 1884-1889.

Shakeel Ahmad, M., Pandey, A. K. and Abd Rahim, N. (2017) Advancements in the development of TiO_2 photoanodes and its fabrication methods for dye sensitized solar cell (DSSC) applications. A review. *Renewable and Sustainable Energy Reviews.* 77**.** 89-108.

Shang, M., Wang, W., Sun, S., Gao, E., Zhang, Z., Zhang, L. and O'hayre, R. (2013) The design and realization of a large-area flexible nanofiber-

based mat for pollutant degradation: an application in photocatalysis. *Nanoscale.* 5**.** 5036-5042.
Shanmugam, M., Baroughi, M. F. and Galipeau, D. (2010) Effect of atomic layer deposited ultra thin HfO_2 and Al_2O_3 interfacial layers on the performance of dye sensitized solar cells. *Thin Solid Films.* 518**.** 2678-2682.
Sharma, G., Singh, S., Kurchania, R. and Ball, R. (2013) Cosensitization of dye sensitized solar cells with a thiocyanate free Ru dye and a metal free dye containing thienylfluorene conjugation. *RSC Advances.* 3**.** 6036-6043.
Sharma, K., Sharma, V. and Sharma, S. S. (2018) Dye-Sensitized Solar Cells: Fundamentals and Current Status. *Nanoscale Research Letters.* 13**.** 381.
Shi, Y., Yang, Y., Dong, G., Jiang, Y., Wei, L., Su, T. and Fan, R. (2017) Three-dimensional flower-like rutile TiO_2 microsphere composed of nanorods: a potential material as light scattering layer for DSSCs. *Chemical Research in Chinese Universities.* 33**.** 298-304.
Sivakumar, R., Ramkumar, J., Shaji, S. and Paulraj, M. (2016) Efficient TiO_2 blocking layer for TiO_2 nanorod arrays-based dye-sensitized solar cells. *Thin Solid Films.* 615**.** 171-176.
Sk, M. A., Ananthanarayanan, A., Huang, L., Lim, K. H. and Chen, P. (2014) Revealing the tunable photoluminescence properties of graphene quantum dots. *Journal of Materials Chemistry C.* 2**.** 6954-6960.
Solbrand, A., Lindström, H., Rensmo, H., Hagfeldt, A., Lindquist, S.-E. and Södergren, S. (1997) Electron transport in the nanostructured TiO_2−Electrolyte system studied with time-resolved photocurrents. *The Journal of Physical Chemistry B.* 101**.** 2514-2518.
Song, S.-H., Jang, M., Yoon, H., Cho, Y.-H., Jeon, S. and Kim, B.-H. (2016) Size and pH dependent photoluminescence of graphene quantum dots with low oxygen content. *RSC Advances.* 6**.** 97990-97994.
Steenfos, H. H., Agren, M. S., Ferber, J. and Luther, J. (1998) Computer simulations of light scattering and absorption in dye-sensitized solar cells. *Solar Energy Materials and Solar Cells.* 54.
Subramaniam, M. R., Kumaresan, D., Jothi, S., Mcgettrick, J. D. and Watson, T. M. (2018) Reduced graphene oxide wrapped hierarchical TiO_2 nanorod composites for improved charge collection efficiency and carrier lifetime in dye sensitized solar cells. *Applied Surface Science.* 428**.** 439-447.
Surya, S., Thangamuthu, R., Senthil Kumar, S. M. and Murugadoss, G. (2017) Synthesis and study of photovoltaic performance on various photoelectrode materials for DSSCs: Optimization of compact layer on nanometer thickness. *Superlattices and Microstructures.* 102**.** 424-441.
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.
Syed Zainol Abidin, S. N. J., Mamat, M. S., Rasyid, S. A., Zainal, Z. and Sulaiman, Y. (2018a) Electropolymerization of poly(3,4-ethylenedioxythiophene) onto polyvinyl alcohol-graphene quantum dot-cobalt oxide nanofiber composite for high-performance supercapacitor. *Electrochimica Acta.* 261**.** 548-556.
Syed Zainol Abidin, S. N. J., Mamat, S., Abdul Rasyid, S., Zainal, Z. and Sulaiman, Y. (2018b) Fabrication of poly(vinyl alcohol)-graphene

quantum dots coated with poly(3,4-ethylenedioxythiophene) for supercapacitor. *Journal of Polymer Science Part A: Polymer Chemistry.* 56**.** 50-58.

Szymanski, L., Surolia, P., Byrne, O., Thampi, K. R. and Stubenrauch, C. (2013) Porous “sponge-like” anatase TiO_2 via polymer templates: synthesis, characterization, and performance as a light-scattering material. *Colloid and Polymer Science.* 291**.** 805-815.

Tachibana, Y., Moser, J. E., Grätzel, M., Klug, D. R. and Durrant, J. R. (1996) Subpicosecond interfacial charge separation in dye-sensitized nanocrystalline titanium dioxide films. *The Journal of Physical Chemistry.* 100**.** 20056-20062.

Taguchi, T., Zhang, X.-T., Sutanto, I., Tokuhiro, K.-I., Rao, T. N., Watanabe, H., Nakamori, T., Uragami, M. and Fujishima, A. (2003) Improving the performance of solid-state dye-sensitized solar cell using MgO-coated TiO_2 nanoporous film. *Chemical Communications.* 2480-2481.

Talib, N. a. A., Salam, F., Yusof, N. A., Alang Ahmad, S. A., Azid, M. Z., Mirad, R. and Sulaiman, Y. (2018) Enhancing a clenbuterol immunosensor based on poly(3,4-ethylenedioxythiophene)/multi-walled carbon nanotube performance using response surface methodology. *RSC Advances.* 8**.** 15522-15532.

Talib, N. a. A., Salam, F., Yusof, N. A., Alang Ahmad, S. A. and Sulaiman, Y. (2017a) Modeling and optimization of electrode modified with poly(3,4-ethylenedioxythiophene)/graphene oxide composite by response surface methodology/Box-Behnken design approach. *Journal of Electroanalytical Chemistry.* 787**.** 1-10.

Talib, N. a. A., Salam, F., Yusof, N. A., Alang Ahmad, S. A. and Sulaiman, Y. (2017b) Optimization of peak current of poly(3,4-ethylenedioxythiophene)/multi-walled carbon nanotube using response surface methodology/central composite design. *RSC Advances.* 7**.** 11101-11110.

Tang, B., Yu, H., Peng, H., Wang, Z., Li, S., Ma, T. and Huang, W. (2018) Graphene based photoanode for DSSCs with high performances. *RSC Advances.* 8**.** 29220-29227.

Tanvi, Saxena, V., Singh, A., Prakash, O., Mahajan, A., Debnath, A. K., Muthe, K. P. and Gadkari, S. C. (2017) Improved performance of dye sensitized solar cell via fine tuning of ultra-thin compact TiO_2 layer. *Solar Energy Materials and Solar Cells.* 170**.** 127-136.

Tarus, B., Fadel, N., Al-Oufy, A. and El-Messiry, M. (2016) Effect of polymer concentration on the morphology and mechanical characteristics of electrospun cellulose acetate and poly (vinyl chloride) nanofiber mats. *Alexandria Engineering Journal.* 55**.** 2975-2984.

Tehare, D. K., Bhande, S., S. Jadhav, V., Gaikwad, S. and Mane, R. (2015) *Significance of compact layers on DSSCs performance of chemically deposited TiO2-based Dye-sensitized solar cells.*

Teng, C.-Y., Nguyen, B.-S., Yeh, T.-F., Lee, Y.-L., Chen, S.-J. and Teng, H. (2017) Roles of nitrogen functionalities in enhancing the excitation-independent green-color photoluminescence of graphene oxide dots. *Nanoscale.* 9**.** 8256-8265.

Thelakkat M., Schmitz C. and Schmidt H-W. (2002) Fully vapor-deposited thin-layer titanium dioxide solar cells. *Advanced Materials.* 14**.** 577-581.

Tiainen, H., Lyngstadaas, S. P., Ellingsen, J. E. and Haugen, H. J. (2010) Ultra-porous titanium oxide scaffold with high compressive strength. *Journal of Materials Science. Materials in Medicine.* 21**.** 2783-2792.

Usami, A. (1997) Theoretical study of application of multiple scattering of light to a dye-sensitized nanocrystalline photoelectrichemical cell. *Chemical Physics Letters.* 277**.** 105-108.

Vinayak, M. V., Lakshmykanth, T. M., Yoosuf, M., Soman, S. and Gopidas, K. R. (2016) Effect of recombination and binding properties on the performance of dye sensitized solar cells based on propeller shaped triphenylamine dyes with multiple binding groups. *Solar Energy.* 124**.** 227-241.

Wan Khalit, W. N. A., Mustafa, M. N. and Sulaiman, Y. (2019) Synergistic effect of poly(3,4-ethylenedioxythiophene), reduced graphene oxide and aluminium oxide) as counter electrode in dye-sensitized solar cell. *Results in Physics.* 13**.** 102355.

Wang, H., Leonard, S. and Hu, Y. (2012) Promoting effect of graphene on dye-sensitized solar cells. *Industrial & Engineering Chemistry Research.* 51**.** 10613–10620.

Wang, J., Qin, M., Tao, H., Ke, W., Chen, Z., Wan, J., Qin, P., Xiong, L., Lei, H., Yu, H. and Fang, G. (2015a) Performance enhancement of perovskite solar cells with Mg-doped TiO_2 compact film as the hole-blocking layer. *Applied Physics Letters.* 106**.** 121104-121110.

Wang, Y., Li, L., Huang, X., Li, Q. and Li, G. (2015b) New insights into fluorinated TiO_2 (brookite, anatase and rutile) nanoparticles as efficient photocatalytic redox catalysts. *RSC Advances.* 5**.** 34302-34313.

Wang, Z. S., Yanagida, M., Sayama, K. and Sugihara, H. (2006) Electronic-insulating coating of $CaCO_3$ on TiO_2 electrode in dye-sensitized solar cells: Improvement of electron lifetime and efficiency. *Chemistry of Materials.* 18**.** 2912-2916.

Wei, L., Chen, S., Yang, Y., Dong, Y., Song, W. and Fan, R. (2016) Reduced graphene oxide modified TiO_2 semiconductor materials for dye-sensitized solar cells. *RSC Advances.* 6**.** 100866-100875.

Wei, L., Wang, P., Yang, Y., Dong, Y., Fan, R., Song, W., Qiu, Y., Yang, Y. and Luan, T. (2017) Enhanced performance of dye sensitized solar cells by using a reduced graphene oxide/TiO_2 blocking layer in the photoanode. *Thin Solid Films.* 639**.** 12-21.

Wei, L., Yang, Y., Xia, X., Fan, R., Su, T., Shi, Y., Li, L. and Jiang, Y. (2015) Band edge movement in dye sensitized Sm-doped TiO_2 solar cells: A study by variable temperature spectroelectrochemistry. *RSC Adv.* 5**.** 70512-70521.

Wongratanaphisan, D., Kaewyai, K., Choopun, S., Gardchareon, A., Ruankham, P. and Phadungdhitidhada, S. (2019) CuO-Cu_2O nanocomposite layer for light-harvesting enhancement in ZnO dye-sensitized solar cells. *Applied Surface Science.* 474**.** 85-90.

Wu, M.-S., Ceng, Z.-Z. and Chen, C.-Y. (2016) Surface modification of porous TiO_2 electrode through pulse oxidative hydrolysis of $TiCl_3$ as an efficient light harvesting photoanode for dye-sensitized solar cells. *Electrochimica Acta.* 191**.** 256-262.

Wu, M.-S., Tsai, C.-H. and Wei, T.-C. (2011) Electrochemical formation of transparent nanostructured TiO_2 film as an effective bifunctional layer for dye-sensitized solar cells. *Chemical Communications.* 47**.** 2871-2873.

Wu, M.-S. and Yang, R.-S. (2018) Post-treatment of porous titanium dioxide film with plasmonic compact layer as a photoanode for enhanced dye-sensitized solar cells. *Journal of Alloys and Compounds.* 740**.** 695-702.
Wu, Q., Tran, T., Lu, W. and Wu, J. (2014) Electrospun silicon/carbon/titanium oxide composite nanofibers for lithium ion batteries. *Journal of Power Sources.* 258**.** 39-45.
Wu, T.-L., Meen, T.-H., Chao, S.-M., Ji, L.-W., Shih, L.-C., Huang, C.-H., Tsai, J.-K. and Wu, T.-C. (2018) Application of ZnO micro rods on the composite photo-electrode of dye sensitized solar cells. *Microsystem Technologies.* 24**.** 285-289.
Wu, X., Wang, L., Luo, F., Beibei, M., Zhan, C. and Qiu, Y. (2007) $BaCO_3$ modification of TiO_2 electrodes in quasi-solid-state dye-sensitized solar cells: Performance improvement and possible mechanism. *Journal of Physical Chemistry C.* 111**.** 8075-8079.
Xia, J., Masaki, N., Jiang, K. and Yanagida, S. (2007a) Fabrication and characterization of thin Nb_2O_5 blocking layers for ionic liquid-based dye-sensitized solar cells. *Journal of Photochemistry and Photobiology A: Chemistry.* 188**.** 120-127.
Xia, J., Masaki, N., Jiang, K. and Yanagida, S. (2007b) Sputtered Nb_2O_5 as a novel blocking layer at conducting glass/TiO_2 interfaces in dye-sensitized ionic liquid solar cells. *The Journal of Physical Chemistry C.* 111**.** 8092-8097.
Yang, L. and Leung, W. W.-F. (2011) Application of a Bilayer TiO_2 Nanofiber Photoanode for Optimization of Dye-Sensitized Solar Cells. *Advanced Materials.* 23**.** 4559-4562.
Yang, X., Zou, W., Su, Y., Zhu, Y., Jiang, H., Shen, J. and Li, C. (2014a) Activated nitrogen-doped carbon nanofibers with hierarchical pore as efficient oxygen reduction reaction catalyst for microbial fuel cells. *Journal of Power Sources.* 266**.** 36-42.
Yang, Y., Peng, X., Chen, S., Lin, L., Zhang, B. and Feng, Y. (2014b) Performance improvement of dye-sensitized solar cells by introducing a hierarchical compact layer involving ZnO and TiO_2 blocking films. *Ceramics International.* 40**.** 15199-15206.
Yao, N., Huang, J., Fu, K., Deng, X., Ding, M., Zhang, S., Xu, X. and Li, L. (2016) Reduced interfacial recombination in dye-sensitized solar cells assisted with NiO:Eu^{3+}, Tb^{3+} coated TiO_2 film. *Sci Rep.* 6**.** 31123.
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.
Yeoh, M.-E. and Chan, K.-Y. (2017) Recent advances in photo-anode for dye-sensitized solar cells: a review. *International Journal of Energy Research.* 41**.** 2446-2467.
Yi, Q., Cong, S., Wang, H., Wang, Y., Dai, X., Zhao, J., Sun, Y., Lou, Y. and Zou, G. (2015) High-stability Ti^{4+} precursor for the TiO_2 compact layer of dye-sensitized solar cells. *Applied Surface Science.* 356**.** 587-592.
Yong, S. M., Tsvetkov, N., Larina, L., Ahn, B. T. and Kim, D. K. (2014) Ultrathin SnO_2 layer for efficient carrier collection in dye-sensitized solar cells. *Thin Solid Films.* 556**.** 503-508.
Yu, C., Zhang, J., Yang, H., Zhang, L. and Gao, Y. (2019a) Enhanced photovoltaic conversion efficiency of a dye-sensitized solar cell based

on TiO2 nanoparticle/nanorod array composites. *Journal of Materials Research.* 34**.** 1155-1166.
Yu, H., Zhang, S., Zhao, H., Will, G. and Liu, P. (2009) An efficient and low-cost TiO_2 compact layer for performance improvement of dye-sensitized solar cells. *Electrochimica Acta.* 54**.** 1319-1324.
Yu, Z., Shen, X., Wu, Y., Yang, S., Ju, D. and Chen, S. (2019b) Enhancement of ascomycin production via a combination of atmospheric and room temperature plasma mutagenesis in Streptomyces hygroscopicus and medium optimization. *AMB Express.* 9**.** 25.
Yue, J., Xiao, Y., Li, Y., Han, G., Zhang, Y. and Hou, W. (2017) Enhanced photovoltaic performances of the dye-sensitized solar cell by utilizing rare-earth modified tin oxide compact layer. *Organic Electronics.* 43**.** 121-129.
Zhang, H., Lv, Y., Yang, C., Chen, H. and Zhou, X. (2018a) One-step hydrothermal fabrication of TiO_2/reduced graphene oxide for high-efficiency dye-sensitized solar cells. *Journal of Electronic Materials.* 47**.** 1630-1637.
Zhang, Q., Chou, T. P., Russo, B., Jenekhe, S. A. and Cao, G. (2008) Aggregation of ZnO nanocrystallites for high conversion efficiency in dye-sensitized solar cells. *Angewandte Chemie International Edition.* 47**.** 2402-2406.
Zhang, Q., Myers, D., Lan, J., Jenekhe, S. and Cao, G. (2012a) Applications of light scattering in dye-sensitized solar cells. *Physical chemistry chemical physics : PCCP.* 14**.** 14982-98.
Zhang, Q., Myers, D., Lan, J., Jenekhe, S. A. and Cao, G. (2012b) Applications of light scattering in dye-sensitized solar cells. *Physical Chemistry Chemical Physics.* 14**.** 14982-14998.
Zhang, W., Gu, J., Yao, S. and Wang, H. (2018b) The synthesis and application of TiO_2 microspheres as scattering layer in dye-sensitized solar cells. *Journal of Materials Science: Materials in Electronics.* 29**.** 7356-7363.
Zhang, Z., Cai, W., Lv, Y., Jin, Y., Chen, K., Wang, L. and Zhou, X. (2019) Anatase TiO_2 nanowires with nanoscale whiskers for the improved photovoltaic performance in dye-sensitized solar cells. *Journal of Materials Science: Materials in Electronics.* 30**.** 14036-14044.
Zhao, A., Zhou, S., Wang, Y., Chen, J., Ye, C. and Huang, N. (2014) *Molecular interaction of fibrinogen with thermally modified titanium dioxide nanoparticles.*
Zheng, F. and Zhu, Z. (2018) Preparation of the Au@TiO_2 nanofibers by one-step electrospinning for the composite photoanode of dye-sensitized solar cells. *Materials Chemistry and Physics.* 208**.** 35-40.
Zhu, K., Neale, N. R., Miedaner, A. and Frank, A. J. (2007) Enhanced charge-collection efficiencies and light scattering in dye-sensitized solar cells using oriented TiO_2 nanotubes arrays. *Nano Letters.* 7**.** 69-74.
Zhu, P., Reddy, M. V., Wu, Y., Peng, S., Yang, S., Nair, A. S., Loh, K. P., Chowdari, B. V. R. and Ramakrishna, S. (2012) Mesoporous SnO_2 agglomerates with hierarchical structures as an efficient dual-functional material for dye-sensitized solar cells. *Chemical Communications.* 48**.** 10865-10867.
Zubair, N. A., Rahman, N. A., Lim, H. N. and Sulaiman, Y. (2017) Production of conductive PEDOT-coated PVA-GO composite nanofibers. *Nanoscale Research Letters.* 12**.** 113.

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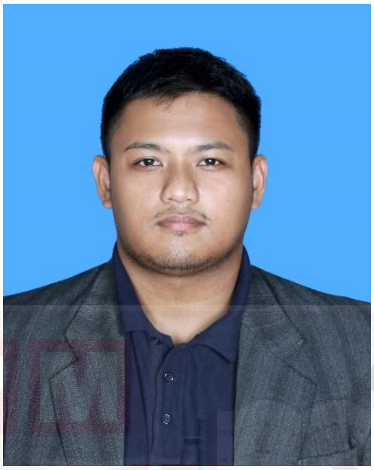

Muhammad Norhaffis Bin Mustafa was born on 26 September 1992 in Hospital Batu Pahat, Johor Darul Takzim. He started his primary education at Sekolah Kebangsaan Seri Beroleh (1999-2004) while his secondary education began at Sekolah Tinggi Batu Pahat (2005-2007) and end at Sekolah Menengah Sains Muar (2008-2009). After that, he attended a matriculation program for one year at Matrikulasi Tangkak, Johor (2010-2011). He started his higher education journey at the Universiti Putra Malaysia and spent 4 years for a degree in Major Chemistry (2011-2014) and 3 years for the Master in Materials Science (2015-2017). Currently, he pursues his Doctoral Philosophy degree in Material Science (2018-2020).

LIST OF PUBLICATIONS

Mustafa, M.N. and Y. Sulaiman, *Optimization of titanium dioxide decorated by graphene quantum dot as a light scatterer for enhanced dye-sensitized solar cell performance.* Journal of Electroanalytical Chemistry, 2020: p. 114516.

Mustafa, M.N. and Y. Sulaiman, *Fully flexible dye-sensitized solar cells photoanode modified with titanium dioxide-graphene quantum dot light scattering layer.* Solar Energy, 2020. 212: p. 332-338.

Mustafa, M.N., et al., *Preparation of TiO_2 compact layer by heat treatment of electrospun TiO_2 composite for dye-sensitized solar cells.* Thin Solid Films, 2020. 693: p. 137699.

Mustafa, M.N., et al., *Light scattering effect of polyvinyl-alcohol/titanium dioxide nanofibers in the dye-sensitized solar cell.* Scientific Reports, 2019. 9(1): p. 14952.

Mustafa, M.N., et al., *Optimization of power conversion efficiency of polyvinyl-alcohol/titanium dioxide as light scattering layer in DSSC using response surface methodology/central composite design.* Results in Physics, 2019. 15: p. 102559.

Mustafa, M.N., et al., *Optimization of power conversion efficiency of polyvinyl-alcohol/titanium dioxide compact layer using response surface methodology/central composite design.* Solar Energy, 2019. 183: p. 689-696.

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