ENHANCEMENT OF TITANIUM DIOXIDE (TiO_2) DYE-SENSITIZED SOLAR CELLS (DSSCs) PERFORMANCE WITH INCORPORATION OF REDUCED GRAPHENE OXIDE (rGO)

AZMAN BIN TALIB

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Special dedication to

My lovely wife and precious children;
Norazlina Binti Ahmad
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ABSTRACT

The purpose of this thesis is to investigate the structural, optical and electrical properties of titanium dioxide (TiO_2) dye-sensitized solar cells (DSSCs) with the incorporation of reduced graphene oxide (rGO). In this experiment, rGO from electrochemical exfoliation, was deposited onto few fluorine-doped tin-oxide (FTO) substrat through spray pyrolysis deposition (SPD) method with different rGO volumes. Then, all the fabricated FTOs went through rutile-phase TiO_2 (r-TiO_2) with hydrothermal synthesis. From DSSCs analysis, 0.50 mL of rGO volume exhibited the best photovoltaic (PV) performance with the efficiency of 2.61% and open-circuit voltage of 0.70 V. The successful synthesis of rGO, incorporated with TiO_2 was confirmed using Raman spectroscopy. The analysis of the samples was done using X-ray diffraction, field emission scanning electron microscopy, ultraviolet-visible spectrophotometry, and incident photon-to-carrier conversion efficiency spectra. Then, another rGO which was produced through Hummers method, was incorporated into anatase-phase TiO_2 (a-TiO_2) as nanocomposite (NC) mixture. After that, through SPD method, the NC mixture was deposited onto few FTOs. The a-TiO_2 was produced by adding TKC-302 into TiO_2 P25 powder. The NC mixture samples significantly contributed towards the improvement of efficiency, when compared with samples without rGO. When 2 mL of rGO was added into a-TiO_2, PV performance achieved the highest efficiency of 3.15% and current density of 5.98 mA/cm^2. Finally, the combination of rGO and a-TiO_2 NC mixture, was overlayered onto r-TiO_2. The 2 mL of rGO/a-TiO_2 NC mixture which was deposited through SPD onto r-TiO_2, exhibited the best PV performance with the highest efficiency of 5.72% and the current density of 10.37 mA/cm^2. The rGO acted as an important material, to maximise the photogenerated electrons of photo-induced charge carriers. The photogenerated electrons from dyes transferred through r-TiO_2, effectively traveled out to the circuit load, which underwent recombination with holes in the solar cells with enhancement of rGO functions.

ABSTRAK

Kandungan tesis ini adalah bagi menyiasat ciri-ciri struktur, optikal dan elektrikal bagi titanium dioksida (*TiO_2*) *dye-sensitized solar cells* (*DSSCs*) dengan gabungan *reduced graphene oxide* (*rGO*). Dalam eksperimen ini, *rGO* hasil dari pengelupasan elektrokimia, disemburkan ke atas beberapa keping *fluorine-doped tin-oxide* (*FTO*) dengan kaedah semburan dengan isipadu *rGO* yang berlainan. Kemudian, kesemua *FTO* tersebut akan melalui proses sintesis hidrotermal fasa-rutil titanium dioksida (*r-TiO_2*). Dari analisis *DSSCs*, sampel *rGO* dengan 0.50 mL menunjukkan prestasi fotovoltaik (*PV*) terbaik dengan kecekapan 2.61% dan voltan litar-terbuka 0.70 V. Kejayaan mensintesis *rGO*, dan digabungkan bersama dengan *TiO_2* ditentusahkan menggunakan spektroskopi *Raman*. Analisis ke atas sampel pula mengunakan difraksi sinar-X (*XRD*), mikroskop elektron pengimbas pelepasan medan (*FE-SEM*), sinar ultraungu (*UV-Vis*) spektrofotometri, dan spektrum kecekapan penukaran foton ke pembawa kejadian (*IPCE*). Kemudian, *rGO* lain yang disintesis melalui kaedah *Hummers*, digabungkan ke dalam larutan fasa-anates *TiO_2* (*a-TiO_2*) sebagai campuran nanokomposit (*NC*), dan disemburkan ke atas beberapa keping *FTO*. Larutan *a-TiO_2* tersebut dihasilkan daripada serbuk *TiO_2* P25 yang dicampurkan dengan TKC-302. Campuran *NC* tersebut memberikan kesan peningkatan pada kecekapan *PV* sel, berbanding tanpa menggunakan *rGO*. Isipadu 2 mL *rGO* yang ditambahkan kepada *a-TiO_2*, menghasilkan kecekapan PV tertinggi iaitu 3.15% dan ketumpatan arus 5.98 mA/cm^2. Dan akhir sekali, kombinasi campuran *rGO* dan *a-TiO_2 NC*, yang disembur ke atas struktur *r-TiO_2 NS*. Isipadu 2 mL campuran *rGO/a-TiO_2 NC*, disemburkan ke atas struktur *r-TiO_2*, menghasilkan prestasi fotovoltaik terbaik dengan kecekapan penukaran tertinggi 5.72% dan ketumpatan arus 10.37 mA/cm^2. *rGO* bertindak sebagai bahan gabungan ke dalam *a-TiO_2*, memaksimumkan bilangan elektron pembawa cas. Membolehkan elektron dari *dye* dipindahkan melalui *r-TiO_2 NS*, bergerak secara efektif ke beban, dengan menghalang penggabungan semula dengan lubang di sel suria dengan meningkatnya fungsi *rGO*.

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LIST OF SYMBOLS AND ABBREVIATIONS

θ	-	angle
λ	-	wavelength
℃	-	degree celsius
β	-	Full Width Half Maximum (FWHM)
l	-	length
w	-	width
t	-	thickness of the films
h	-	hour
η	-	efficiency
D	-	crystallite size
K	-	Scherrer constant
E	-	applied potential (V)
i	-	current response (A)
v	-	scan rate ($mV.s^{-1}$)
ρ	-	resistivity of the films
R_s	-	sheet resistance
α	-	absorption coefficient
E_g	-	energy bandgap
R	-	resistivity
$\hbar v$	-	photon energy
0D	-	zero-dimensional
1D	-	one-dimensional
2D	-	two-dimensional
3D	-	three-dimensional
μm	-	micrometre
Abs	-	absorbance

CE	-	counter electrode
Cl	-	chloride
CO_2	-	carbon dioxide
C	-	carbon
DSSCs	-	dye-sensitized solar cells
FE-SEM	-	Field Emission – Scanning Electron Microscope
FF	-	fill factor
FTO	-	fluorine doped tin-oxide
FWHM	-	full width half maximum
GW	-	giga watt
H	-	hydrogen
HCl	-	hydrochloric acid
IR	-	infrared
I	-	current (A)
V	-	voltage (V)
ITO	-	indium doped tin-oxide
J_{sc}	-	short-circuit current density (mA/cm^2)
MΩ	-	mega ohm
MW	-	mega watt
Na	-	sodium
NC	-	nanocomposite
NFs	-	nanoflowers
nm	-	nanometre
NPs	-	nanoparticles
NRs	-	nanorods
O	-	oxygen
OH	-	hydroxide
p	-	positive
Pt	-	platinum
PCE	-	power energy conversion efficiency
PV	-	photovoltaic
RE	-	renewable energy
RMS	-	root mean square

Si	-	silicone
SnO_2	-	tin oxide
Sn	-	tin
T	-	transmittance
TBOT	-	titanium butoxide
TCO	-	transparent conducting oxide
Ti	-	titanium
TiO_2	-	titanium dioxide
$a\text{-}TiO_2$	-	anatase-phase of titanium dioxide
$r\text{-}TiO_2$	-	rutile-phase of titanium dioxide
DI	-	de-ionized
EDX	-	energy dispersive x-ray
CVD	-	chemical vapour deposition
EIS	-	elechtrochemical impedance spectroscopy
GO	-	graphene oxide
rGO	-	reduced graphene oxide
H_2O_2	-	hydrogen peroxide
H_2SO_4	-	sulphuric acid
H_3PO_4	-	phosphoric acid
$KMnO_4$	-	potassium permanganate
mL	-	mili litre
SPD	-	spray pyrolysis deposition
SDS	-	sodium dodecyl sulfate
TBP	-	4-*ter*-butylpyridine
UV	-	ultraviolet
UV-Vis	-	ultraviolet-visible
V_{oc}	-	open-circuit voltage (V)
XRD	-	x-ray diffraction
atm	-	atmosphere
RF	-	radio frequency
Ru	-	ruthenium
I^-/I_3^-	-	iodide/triiodide
ZnO	-	zinc oxide

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The energy produced by fossil fuels has become today's primary driver in the growth of civilization. The produced energy will affect industrial and agricultural development of any country. Therefore, the survival of a country relies on the continuous conservation of resources. The high availability of fossil fuels will add to a nation's economic richness and materials standards. The intensive use of fossil fuels could affects the atmosphere and ecology [1]. With the demand for electricity, several countries are searching for environmentally sustainable, green and non-conventional alternatives [2]. Solar power is one of the possible forms of green electricity. Solar energy becomes an effective energy source and a critical energy resource since it is one of the renewables that may be utilized when other supplies including fossil fuels have been exhausted. With the high promotion of solar panels, there have been developments in the number of innovations that utilize solar cells in solar energy science.

The so-called solar cells is a photovoltaic structure used primarily to transform solar radiation to electricity dependent on sunlight photosynthesis. The solar cells is an efficient and useful system because of its electricity production capabilities that have been explored extensively in a variety of recent reports [3], [4]. As summarized in Figure 1.1, the solar cells are categorized into three generations based on the time period in which it was discovered. Initially, thin silicon wafer was used to manufacture most of the solar cells. They are also known as the first-generation solar cells. Then, the third generation solar cells are the most advanced cells. They have multijunction and hot carrier cells, consist of nanomaterials and polymers and are able to exhibit the optimum features compared to earlier generations. They are more efficient, less expensive and adopt the up-conversion, down-conversion, and solar thermal technologies [5].

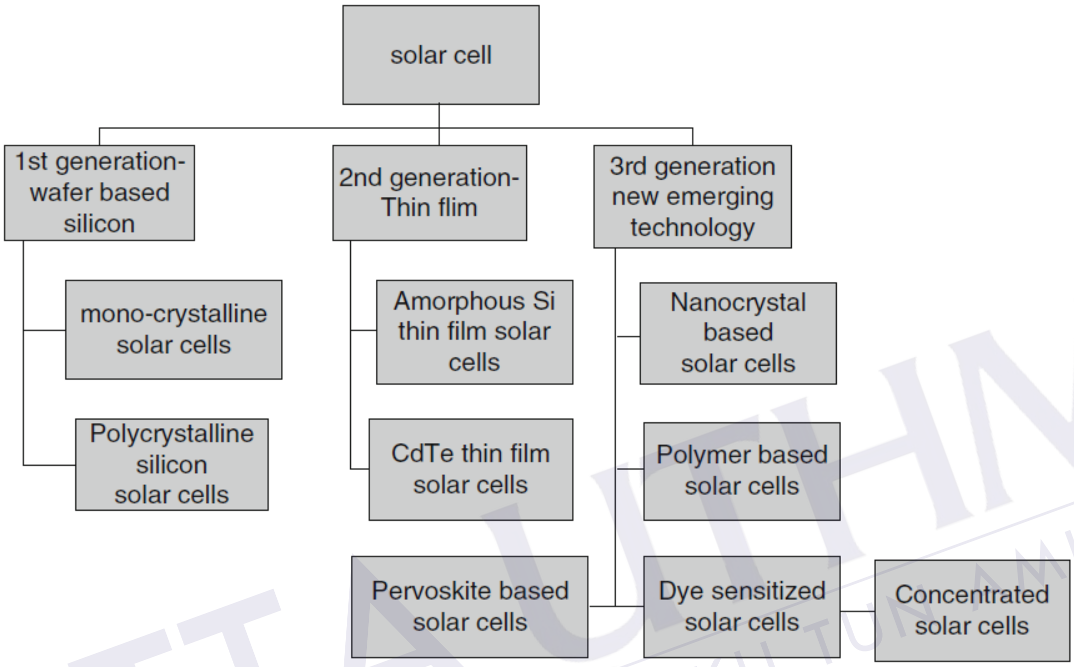

Figure 1.1: Generations of solar cells technology [5].

Dye-sensitized solar cells (DSSCs) is the third generation solar technology which provides effective charge separation that allows electricity to be generated even in low light condition. The first DSSCs was invented in 1991 based on artificial photosynthesis system to generate electricity [6]. Currently, DSSCs are still in the research phase to enhance its efficiency. The average efficiency of this new type of solar cells is 15% [7], [8]. Overall, DSSCs device manufacturing is considered as a low cost, simple and promising technique to provide high performance of electrical generation efficiency. DSSCs are currently in the testing stage to increase their performance. There are five components of a DSSCs. They are translucent fluoride-doped tin oxide (FTO) glass substrate, semiconductors material, dye sensitizer adsorber on the surface of the semiconductors, electrolytes, and counter electrodes (CE) [7].

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