UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electronic and Computer Engineering

FABRICATION OF SOLAR FABRIC USING TITANIUM DIOXIDE NANOWIRES BASED ON DYE SENSITIZED SOLAR CELL TECHNIQUE

Noor Faridah binti Amat

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NOOR FARIDAH BINTI AMAT

A thesis submitted
in fulfillment of requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Fabrication of Solar Fabric using Titanium Dioxide (TiO_2) Nanowires based on Dye Sensitized Solar Cell (DSSC) Technique" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATION

To my beloved mother and family

ABSTRACT

Solar fabric is the third generation of photovoltaic device that converting solar energy to electrical energy to produce electricity. In order to reduce the cost manufacturing of solar cell, solar fabric is introduced as a cheaper manufacturing cost to generate solar energy. In this research work, it presents a comprehensive review on the synthesis, structure characterization, the performance of nanostructures in term of conductivity and lastly, fabrication process to create the solar fabric. Titanium dioxide (TiO_2) has been used to develop nanowires as the characteristics are better than other semiconductor material. The nanowires are succeeding to develop via hydrothermal method to fabricate solar fabric that applying dye sensitized solar cell (DSSC) technique. Generally, there are various techniques to develop the nanowires. But this research work, hydrothermal method, sol-gel method and electrospinning technique were conducted in the laboratory. By comparing the result of the three methods, only sol-gel method unsuccessfully to develop nanowires. Even though electrospinning is succeeding to produce nanowires, but, the quantity is smaller, the process takes a long time and use high voltage. The characteristic of the nanowires is measured by analyzing using FESEM, XRD, BET, UV-Vis and conductivity testing to figure out the quality or the best nanowires. The best 4 samples has been figured out and it was used to fabricate the solar fabric. The solar fabric has applied DSSC technique. The best 4 sample which are A, B, C and D were used to fabricate the solar fabric and the efficiency of each device have been measured using a solar simulator and potentiostat. The devices have been further investigated using electrochemical impedance spectroscopy (EIS) to measure the interaction of internal resistance in the devices. From the results, sample D becomes the best TiO_2 nanowires compared to the rest of the samples, which has achieved a high performance at 1.46%. On the other hand, sample B showed low efficiency at around 0.08%, while sample A displayed about 0.4%, and sample C exhibited 1.2%.

ABSTRAK

Kain solar adalah alat 'photovoltaic' generasi ketiga yang menukarkan tenaga solar kepada tenaga elektrik untuk menghasilkan elektrik. Dalam usaha mengurangkan kos pembuatan panel solar, kain solar diperkenalkan sebagai satu cara untuk mengurangkan kos pembuatan untuk menghasilkan tenaga elektrik. Dalam penyelidikan ini, ia menerangkan beberapa pandangan yang komprehensif dalam sintesis, struktur karakter, pencapaian nanostruktur dalam konduktiviti dan akhir sekali, proses fabrikasi untuk menghasilkan kain solar. Titanium dioksida (TiO_2) telah dipilih untuk menghasilkan nanowayar berbanding dengan bahan semikonduktor yang lain. Nanowayar berjaya dihasilkan menggunakan teknik 'hydrothermal', nanowayar akan digunakan untuk menghasilkan kain solar dengan menggunakan teknik DSSC. Asasnya, pelbagai teknik boleh digunakan untuk menghasilkan nanowayar. Tetapi didalam penyelidikan ini, teknik 'hydrothermal', teknik sol-gel dan teknik 'electrospinning' telah digunakan untuk menghasilkan nanowayar. Dengan membandingkan 3 perbezaan cara tersebut, hanya teknik sol-gel sahaja gagal menghasilkan nanowayar. Walaupun, teknik 'electrospinning' berjaya menghasilkan nanowayar tetapi ia meghasilkan kuantiti yang sangat sedikit dan mengambil masa yang lama untuk menghasilkan nanowayar serta menggunakan voltan yang tinggi. Ciri-ciri nanowayar dikenalpasti dengan menjalankan analisa menggunakan FESEM, XRD, BET and UV-Vis dan ujian konduktiviti turut dijalankan untuk mengetahui sampel nanowayar yang terbaik. Empat sampel telah dipilih dan digunakan untuk menghasilkan kain solar dengan menggunakan teknik DSSC. Empat sampel nanowayar yang terbaik telah dipilih untuk menghasilkan kain solar dan akan diuji dengan menggunakan solar simulator dan 'potentiostat' untuk mengetahui keupayaan menghasilkan tenaga elektrik. Empat sampel tersebut dilabel sebagai A, B, C dan D. Kemudian alat ini dikaji dengan lebih terperinci menggunakan 'electrochemical impedance spectroscopy (EIS)' untuk mengukur interaksi rintangan dalaman di dalam sel solar. Daripada keputusan yang diperolehi, sampel D memiliki 'nanowires' terbaik berbanding dengan sampel lain dimana sampel D mencapai 1.46%. Selain itu, sample B menunjukkan keupayaan yang rendah sekitar 0.08%, manakala sampel A menunjukkan 0.4% dan sampel C menunjukkan 1.2%.

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LIST OF ABBREVIATIONS

PV	-	Photovoltaic
CO_2	-	Carbon Dioxide
TiO_2	-	Titanium Dioxide
DSSC	-	Dye Sensitized Solar Cell
CdS	-	Cadmium Sulphide
GaAs	-	Gallium Arsenide
CdTe	-	Cadmium Telluride
InP	-	Indium Phosphide
CE	-	Counter Electrode
Pt	-	Platinum
WE	-	Working Electrode
PCE	-	Power Conversion Efficiency
FESEM	-	Field Emission Scanning Micscopy Measurement
BET	-	Brunauer, Emmett, And Teller
XRD	-	X-Ray Diffraction
Uv-Vis	-	Ultraviolet-Visible Spectroscopy
SnO_2	-	Tin Dioxide
ZnO	-	Zinc Oxide
Nb_2O_5	-	Niobium Pentoxide
FTO	-	Fluorine-Doped Tin Oxide
NP	-	Nanoparticles
NW	-	Nanowires
1D	-	One-Dimensional
VLS	-	Vapor Liquid Solid
CVD	-	Chemical Vapour Deposition

MOCVD	-	Metal Organic Chemical Vapor Deposition
HFCVD	-	Hot Filament Chemical Vapor Deposition
HCl	-	Hydrochloric Acid
NaOH	-	Sodium Hydroxide
KOH	-	Potassium Hydroxide
SEM	-	Scanning Electron Microscopy
N_2	-	Nitrogen
PANI-EB	-	Polyaniline Emeraldine Base
NMP	-	N-Methylpyrrolidone
EIS	-	Electrochemical Impedance Spectroscopy
N719	-	cis-di(thiocyanato)-N,N′-bis(2,2′-bipyridyl-4-carboxylic acid-4′-tetrabutylammonium carboxylate)ruthenium(II)
N3	-	cis-Bis(isothiocyanato)bis(2,2’-bipyridyl-4,4’-dicarboxylato ruthenium(II)
LPTA	-	Lembaga Perlesenan Tenaga Atom
P3HT	-	Poly(3-Hexyl Thiophene)
PCBM	-	Phenyl-C61-Butyric Acid Methyl Ester
V_{OC}	-	Open Circuit Voltage
J_{SC}	-	Short Circuit Current
FF	-	Fill Factor
$TiCl_4$	-	Titanium Tetrachloride
$H_2Ti_3O_7$	-	Hydrogen Titanate
NaCl	-	Sodium Chloride
$NaKTi_3O_7$	-	Sodium Potassium Titanate
KCl	-	Potassium Chloride

LIST OF SYMBOLS

λ	-	Lambda
η	-	Efficiency
Na^{+}	-	Sodium ion
K^{+}	-	Chloride ion
Ti^{4+}	-	Titanium ion
Cl^{-}	-	Chloride ion
I^{-}	-	Iodide
I^{3-}	-	Triiodide
H^{+}	-	Hydrogen ion
OH^{-}	-	Hydroxyl ion

LIST OF PUBLICATIONS

Journal:

Mohd Azlishah Othman, Badrul Hisham Ahmad, Noor Faridah Amat, December, 2013. An Overview of Nanonet Based Dye-Sensitized Solar Cell (DSSC) In Solar Cloth, *Journal of Semiconductor Technology and Science, Vol.13, No.6*, pp.635-646. *(Scopus and ISI indexed IF=0.6)*

Noor Faridah Amat, Mohd Azlishah Othman, Badrul Hisham Ahmad and Jose Rajan, February 2015. Solar Cloth Using TiO_2 Nanostructures Based DyeSensitized Solar Cell Technique, *ARPN Journal of Engineering and Applied Sciences,Vol. 10, No. 2,* pp. 709-713.

Conference paper:

Mohd Azlishah Othman, Noor Faridah Amat, Badrul Hisham Ahmad, Jose Rajan, 2014. Electrical Conductivity Characteristic of TiO_2 Nanowires From Hydrothermal Method *Journal of Physics: Conference Series 495 (2014) IOP Publishing*, pp. 1-7 (Scietech 2014, Jakarta, Indonesia.)

CHAPTER 1

INTRODUCTION

1.1 Research Background

Nowadays, the green technology field has become a key element in the research area. In fact, researchers have recently explored this field to carry out studies on a new technology to produce clean energy for use in daily life. Moreover, the depletion of fossil energy has led us to three possible options to generate electricity, such as carbon fuel based sources, nuclear power, and renewable sources like solar energy, which have become important. However, carbon fuel based sources have a negative impact on the environment as they increase the atmospheric carbon dioxide (CO_2) levels and provoke catastrophic climate changes. The nuclear power sources, on the other hand, require hundreds of Giga watt level nuclear power stations to be built and no practical method has been found to dispose of dangerous nuclear fuel wastes. Meanwhile, as for solar source, this energy is freely available and it is supplied directly to our home. Thus, harnessing energy from sunlight has been chosen as an option to generate electrical energy to provide us with energy for daily life and one need not fear about the energy supply line. Nevertheless, this area is indeed a challenge to researchers in ensuring that the new technology is clean, low cost, and high in efficiency.

Photovoltaic (PV) device is one device that generates useful electric energy from sunlight through multiple steps of energy conversion processes (Kim, 2009). Photovoltaic, also recognized as solar cells, is an electronic device that converts sunlight directly to electricity. In 1839, a French physicist named Edmund Becquerel discovered the photovoltaic effect (Kim, 2009) (Cook et al., 1995) (Dahl, 1999). Becquerel found that one of two identical electrodes for certain materials produced small amounts of electric when it was exposed to light (Hersch and Zweibel, 1982). Soon afterwards, Heinrich Hertz produced selenium photovoltaic cells that converted light to electricity at 1% to 2% of efficiency in the 1870s (Cook et al., 1995). Then, photovoltaic cells were commercialized in the 1940s and 1950s (Hamilton, 2011) when the Czochralski produced photovoltaic cells from pure crystalline silicon, which used p-n junction and produced an efficiency at 4% (Hersch and Zweibel, 1982). In this period, there were also photovoltaic cells made of cadmium sulphide (CdS), gallium arsenide (GaAs), cadmium telluride (CdTe), and indium phosphide (InP). However, each material had its own disadvantage. For example, cadmium which is used in cadmium sulphide and cadmium telluride photovoltaic cells, is a toxic element, while gallium arsenide based photovoltaic cells are very expensive to produce, and the indium used in indium phosphide photovoltaic cells is limited. Nonetheless, silicon-based photovoltaic cells, even though have been regarded as the most promising photovoltaic technology, the production cost of silicon photovoltaic cells is high or expensive.

Furthermore, most photovoltaic devices, also known as solar cells, are developed using semiconductor materials that convert solar energy directly to electricity (Goncher and Solanki, 2008) (Green, 2002). The process of converting solar energy to electricity is called photovoltaic (PV) effect (Cook et al., 1995). The electricity flows between two types of semiconductors, p-n types, when both types (p-type and n- type) are placed in close contact with each other (Cook et al., 1995) and are exposed to light. Moreover, sunlight with photon energies is greater than semiconductor band gap energy as it is absorbed by excited electrons from the valence band of the semiconductor p-type to gain adequate energy to break their boundaries (Green, 2002). The sunlight provides the electrons with the energy needed to leave their bounds and cross the junction between two types of semiconductors. Besides, the photon energy is greater than semiconductor band gap and supports these electrons to escape from their normal positions in the atom (Cook et al., 1995). When the covalent bond in the valence band is broken, the electron is free to move in the crystal lattice of the semiconductor n-type to produce electricity, leaving holes behind in the p-type flow in the opposite direction (Zhang and Shakouri, 2002) (Cook et al., 1995). Meanwhile, in the p-n junction, the energy required to break a covalent bond known as energy gap (Eg); if the photon energy is less than the energy gap, it does not have enough energy to break a covalent bond and free an electron for conduction (Zhang and Shakouri, 2002) (Cook et al., 1995). Since electrons cannot occupy the forbidden states between the valence and the conduction bands, a photon with energy less than the energy gap cannot be absorbed and will pass through the device (Cook et al., 1995). Figure 1.1 shows the effect of photovoltaic where the sunlight hits a solar cell and a semiconductor material absorbs the photon knocks the electrons from their atoms allow the electrons to flow freely through the material to produce electricity.

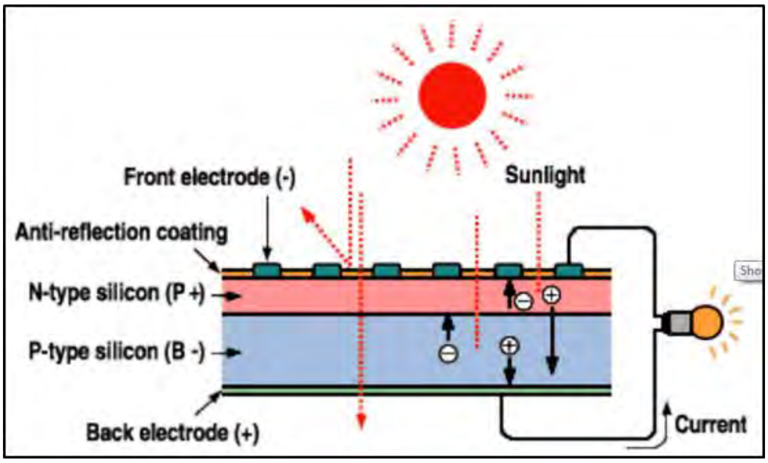

Figure 1.1: The photovoltaic effect (Hamilton, 2011)

In a p–n junction cell, the light absorption and photogenerated carrier transport processes occur side by side throughout the device (Green, 2002). On the other hand, dye-sensitised cell exhibits a different principle of operation (Green, 2002) as the absorption occurs at a very specific location at the dye molecules, which are attached to the semiconductor material medium, as illustrated in Figure 1.2. In fact, for any solar cell working principle, 3 basic operations that consist of absorption, separation, and collection take place (Karmakar and Ruparelia, 2011). Moreover, each solar cell optimizes different working principles to achieve better efficiency. Basically, dye sensitized solar cell (DSSC) is a thin layer of solar cell that is formed in sandwich arrangements of two transparent conducting oxide electrode; counter electrode (CE) coated with platinum (Pt) and working electrode (WE) coated with semiconductor material, such as titanium dioxide (TiO_2), zinc oxide (ZnO), tin dioxide (SnO_2), niobium pentoxide (Nb_2O_5), and many more. For example, Figure 1.2 shows TiO_2 nanoparticles coated with light-sensitive dye and surrounded by electrolyte. The interaction between counter electrode and working electrode that consists of dye is anchored on TiO_2 nanoparticles and it is surrounded by an electrolyte to create a roadway for the electrons (electricity) to flow through the cell. Besides, the best efficiency of DSSC that applied nanoparticles obtained was in the range of 12% (IRENA, 2012), but commercial efficiencies were low as they were typically under 4% to 5% (IRENA, 2012). Other than that, nanorods based DSSC showed improved performance with efficiency at 6.2%, compared to nanoparticles based DSSC, which achieved an efficiency at 4.3 % (Soon et al., 2008). More recently, TiO_2 nanostructures were used to produce DSSC that achieved power conversion efficiency (PCE) at 4.66 % (Wu et al., 2013).

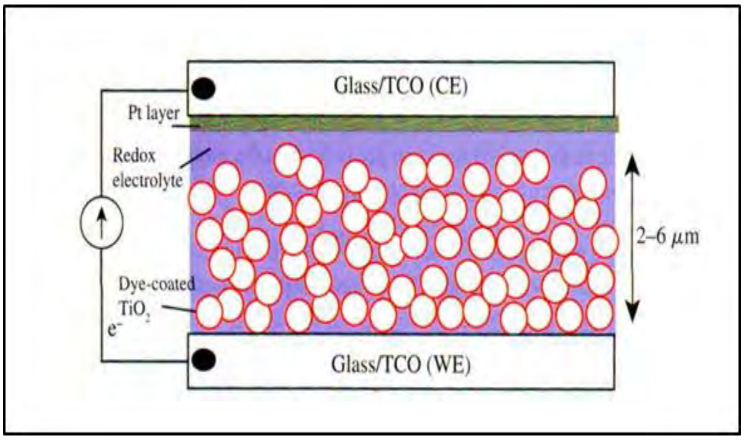

Figure 1.2: Structure of DSSC (Lamant, 2010)

Apart from that, in order to develop a low power energy device, a 'solar fabric'; a piece of fabric integrated with solar cells, is further discussed. Sundarrajan et al., (2010) stated that solar cells that are based on polymers have captivated the minds of scientists for powering low energy applications, such as indoor furnishings, cloths, fabric and personal electronic gadgets. Solar cells on flexible platforms are attached to the fabrics to power low energy devices. Besides, prototype materials have been released by various companies, such as Solartex, Bogner/Mustang, and Maier into the market (Sundarrajan et al., 2010). In this project, the third generation of photovoltaic device, which is the Dye Sensitized Solar Cell (DSSC), was applied to develop solar fabric. In 1991, Prof Michael Grätzel invented the DSSC as a new generation of photovoltaic device and demonstrated its function for the first time (Jena et al., 2012) (Byranvand, Kharat, and Badiei, 2012), which promised low manufacturing cost technology to harvest energy from the sunlight (Jiao, Zhang and Meng, 1991). At present, DSSC has become a popular area to explore for some researchers in order to improve and increase the efficiency of the DSSC to absorb the solar energy and produce more electricity.

In addition, one dimensional (1D) nanostructures, which are also known as nanowires, have been chosen as nanostructures morphology to act as a network in order to improve the performance of the solar cell (Baxter and Aydil, 2005), especially in third generation photovoltaic devices where the efficiency of the device to absorb the solar energy will be increased and it can help the device to generate more electricity. Hence, this project applied the 1D nanostructure in solar fabric, which is a type of photovoltaic device, that applied the DSSC technique. By using Solar fabric with the application of the DSSC working principle was made from a non-woven fiber fabric in which a dye-anchored wide band gap semiconductor, which was the electron conductor, formed a percolating network in a polymer medium. For instance, the solar fabric can be installed in homes or offices as a curtain to absorb sunlight to produce electricity for electrical appliances. The network of the 1D nanostructures or fiber would have superior percolation behaviour compared to nanoparticles analogous. Besides, nanowires provided a direct path (Law et al., 2005) (Baxter and Aydil, 2005) for the electrons to move from a photo excitation state to wide band gap of semiconductor network to generate electrical energy, which had been anchored with light sensitive dye on its surface. Moreover, in the solar fabric, the TiO_2 nanowires were coated with dye-sensitized light and were surrounded in a polymeric hole-conducting medium.

In addition to this project, charge collection efficiency had been one of the hot issues that had been looked into. The charge diffusion in this case was ambipolar in nature, which occurred when one type of carrier moved in a sea of the opposite charge. Furthermore, the efficiency of charge collection, which depended on chemical capacitance that measures the change in electron density as a function of a small variation in applied potential; electron density; electron transport resistance; and charge recombination resistance is measured. Lastly, the performance of the charge movement in the device also will be measured in terms of conductivity that showed the capability of the charge in the material itself. As a conclusion, a lot of aspects had to be weighted in order to develop best solar fabric such the charge movement, material, manufacturing and physical characteristics such easy-going, convenient, and more.

1.2 Problem Statement

Nowadays, solar cells or solar panel has become a popular device installed in homes or offices as a device to supply electricity. In Malaysia, electricity is generated from burning limited resources such as oil, coal, natural gas that have huge consequences for the environment. According to The Star (22th April 2015), the primary source of demand comes from the industrial sector is about 45% for 2012. While, the residential and commercial use 33% and 21%. In order To promote the renewable source to generate electricity, Malaysia government provides one scheme to use the PV solar cell to capture solar energy for use in residential and commercial sector. The device can be placed on roofs of houses and buildings, but it so much cost to install. So that, the third generation of solar cells known as DSSC has been introduced to develop the device from a variety of new materials and also to offer low cost manufacturing. The revolution of solar cell began with the traditional solar cell that was transformed into a thin film, and at present, the DSSC that consists of semiconductor material in nano scale, organic dyes, and conductive plastics that use conventional printing press technology have been introduced. On top of that, due to the high demand to develop solar cells that are easy to use and low in cost, solar fabric has been introduced as a new device to generate electricity from the sun. Solar fabric is made from a non-woven fiber that applies the DSSC technique, which consists of semiconductor material nanostructures in a polymer medium. The performance of the semiconductor material in the polymer medium had been measured in this study.