Faculty of Engineering

# FABRICATION AND CHARACTERIZATION OF TITANIUM DIOXIDE BASED DYE SENSITIZED SOLAR CELL

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Final Year Project Report ☑

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# FABRICATION AND CHARACTERIZATION OF TITANIUM DIOXIDE BASED DYE SENSITIZED SOLAR CELL

ANDRE ANDING ANAK TEDONG

A final year project report submitted in partial fulfilment of
the requirement for the degree of
Bachelor of Engineering (Hons) in Electronics (Telecommunications)

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Dedicated to my beloved parents who always bestow me sustainable motivations and encouragement

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# ABSTRACT

In this study, Dye-Sensitized Solar Cells (DSSC) were fabricated using Titanium Dioxide ($TiO_2$) as a metal oxide semiconducting layers dyed with anthocyanin dyed with one type of natural plant extracts. $TiO_2$ solutions with different synthesizing temperatures that are 50 °C, 60 °C, and 70 °C were synthesized using Sol-gel method. The $TiO_2$ solution is deposited on glass substrates using spin coating method. The structural, optical and electrical properties of $TiO_2$ thin film were characterized using scanning electron microscopy (SEM), Ultraviolet -Visible (UV-Vis) spectroscopy, and Current-Voltage (I-V) characteristics test. The effects of different synthesizing temperature of $TiO_2$ solution is studied. The structural analysis shows that $TiO_2$ thin film with 60°C of synthesis temperature exhibits the most porous structure and its particle size is smaller if compared to others with synthesis temperature of 50°C and 70°C. Besides that, the optical properties show that $TiO_2$ thin film with 60 °C of synthesis temperature also provide the sharpest peak absorption of 0.40 at the wavelength of 575.50 nm and lower band gap energy of 3.10 eV compared to $TiO_2$ solution synthesized with temperature of 50 °C and 70 °C. The performance of DSSC based on $TiO_2$ synthesized with different temperatures were tested for the electrical properties at two different condition which are light and dark condition. The organic dye used in fabrication of $TiO_2$ based DSSC is beetroot plant that contains anthocyanin extracts. Based on I-V curve results, DSSC sample fabricated with 60 °C of $TiO_2$ solution shows the highest reading of short-circuit current at 0.80 mA and open-circuit voltage at 0.94 V, compared to the DSSC sample with 50 °C and 70 °C synthesizing temperature. The energy conversion efficiency, $\eta$ for DSSC sample fabricated with 60 °C of $TiO_2$ solution is the highest, that is at 0.316 %, compared to other DSSC sample with 50 °C and 70 °C $TiO_2$ solution that is at 0.158 % and 0.230 %, respectively. Hence, at temperature of 60 °C is the most optimum temperature for synthesizing of $TiO_2$ solution by sol-gel method for DSSC application.

# ABSTRAK

Dalam kajian ini, DSSC telah direka bentuk dengan menggunakan lapisan komponen semikonduktor iaitu TiO2, dan di celup dengan pewarna semulajadi daripada ekstrak anthocyanin tumbahan bit. Bahan semikonduktor TiO2 telah disintesis dengan pelbagai suhu proses sintesis iaitu 50 °C, 60 °C, dan 70 °C sebagai parameter yang di kaji. TiO2 telah di sintesis dengan menggunakan kaedah Sol-gel. Bahan semikonduktor TiO2 di depositkan pada permukaan substrat kaca dengan menggunakan teknik spin coating. Sehubungan dengan itu, ciri struktur permukaan, optikal dan elektrik filem nipis TiO2 telah di peroleh menggunakan scanning electron microscopy (SEM), Ultraviolet - Visible (UV-Vis) spectroscopy, dan ujian Current-Voltage (I-V) characteristics. Kepelbagaian dalam suhu sentisis cecair bahan semikonduktor TiO2 telah memberi kesan dalam aplikasi DSSC dan di kaji dengan lebih teliti. Cisi struktur yang telah di peroleh menunjukkan filem nipis TiO2 dengan suhu sintesis 60 °C mempunyai struktur partikel yang paling berliang dan bersaiz kecil jika dibandingkan dengan filem nipis TiO2 dengan suhu sintesis 50 °C dan 70 °C. Selain itu, ciri optikal menunjukkan filem nipis TiO2 dengan suhu sintesis 60 °C memberi bacaan penyerapan cahaya yang paling tinggi iaitu pada skala 0.4 dalam wavelength 575.50 nm, dan juga mempunyai bacaan band gap yang paling rendah jika di bandingkan dengan TiO2 sintesis suhu 50 °C dan 70 °C. Prestasi DSSC berdasarkan bahan cecair TiO2 yang di pelbagaikan sintesis suhu di uji untuk ujian ciri elektrik, di uji dalam dua kondisi, iaitu dalam terang cahaya dan di dalam gelap. Berdasarkan bacaan I-V curve yang di peroleh daripada ujian ciri elektrik, sample DSSC direka bentuk dengan cecair TiO2 mempunyai suhu sintesis 60 °C menunjukan bacaan arus elektrik yang tertinggi iaitu 0.80 mA dan arus voltan tinggi iaitu 0.94 V, jika di banding dengan sample lain yang mempunyai suhu sintesis 50 °C dan 70 °C. Dengan itu, efisyensi penukaran tenaga, η untuk DSSC berdasarkan bahan cecair TiO2 mempunyai suhu sintesis 60 °C menunjukan bacaan tertinggi, iaitu 0.316 % efisyensi berbanding dengan TiO2 sintesis suhu 50 °C dengan bacaan 0.158% efisyen dan 70 °C dengan bacaan 0.230% efisyen. Sehubungan dengan itu, suhu sintesis cecair TiO2 pada takat 60 °C merupakan suhu sintesis optimum untuk di aplikasikan dalam reka bentuk DSSC dengan menggunakan sol-gel.

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| | | |
|---|---|---|
| DSSC | – | Dye-Sensitized Solar Cell |
| $TiO_2$ | – | Titanium Dioxide |
| Si | – | Silicon |
| PV | – | Photovoltaic |
| a-Si | – | Amorphous Silicon |
| Cd-Te | – | Cadmium Telluride |
| CIGS | – | Copper Indium Selenide |
| Cd | – | Cadmium |
| I | – | Indium |
| Pt | – | Platinum |
| ZnO | – | Zinc Oxide |
| $SnO_2$ | – | Tin Dioxide |
| FTO | – | Fluorine-doped Tin Oxide |
| TTIP | – | Titanium isopropoxide |
| PEG | – | Polyethylene Glycol |
| SEM | – | Scanning Electron Microscopy |
| UV-Vis | – | Ultraviolet Visible |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Overview

As the years passed by, the consumption of global energy is increasing rapidly due to the increase in population all around the world. Throughout the years, global energy consumption increases drastically and it eventually cause the demands of natural resources for example, petroleum and natural gas. These energy resources that is non-renewable can be found underneath the surface of the Earth but it requires a long period of time and hardly being replaced because the amount of these natural resources are decreasing rapidly year by year. Therefore, the worst possible outcomes are when we will have to face limited amount of resource that could lead to the rise of the harvesting expenses. As the energy consumption gradually increase, the climatic disruption also will increase and affect the whole earth populations. In this generation, fossil fuels have been generating a reasonable percentage of power, which emit many gasses, such as nitrous oxide and sulfur dioxide. This gasses pollutes the environment and causes global warming along with climate change. Besides that, fossil fuel combustion also will lead to the Greenhouse effect. The public awareness rise significantly due to issues of sustainable energy source from the past until now, especially in high development countries that required high demand of electricity. Therefore, people started to rely on alternative energy source that is renewable. One of the more environmental friendly choice of energy source is the solar cell, which also named as photovoltaic cell. Up to 10% efficiency we can from solar cells which covers 0.1 % of the earth's surface, which can satisfy the needs of energy for mankind for the time being [1].

The development of electrical energy storage is ongoing, and solar cells are recognized as a clean energy device because it does not produce carbon dioxide and renewable [2]. Solar cell works to converts to electricity with specific wavelengths. Solar cells technologies are traditionally grouped into categories of three generations. The

earliest generation of solar cell that currently being used in practice are made from silicon (Si). Si solar cells still dominate the market and widely used because of its good performance, as well as their high stability [3]. In terms of single cell PV device, Si based solar cell are said to be the most efficient, and Si is easily found because it can be found abandoned on earth, most abundant materials second to oxygen [4]. Thin-film cell is known to be the next generation of solar cell. These solar cell comes out with three types that are amorphous silicon (a-Si), Cadmium Telluride (Cd-Te), Copper Indium Selenide (CIGS). The main difference between first generation to the second, is the material used in the cell fabrication. The design of thin-film solar cell allows them to have better efficiency and only requires lower cost among the previous generation of solar cell [5]. However, the material used in producing the cell are getting rare and highly toxic, for example Indium and Cadmium [3]. Therefore, many research is being conducted to produce a new generation of solar cell that is more applicable.

Dye Sensitized Solar Cell (DSSC) of the third generation solar based device has turn up to be a relatively new category of less costly solar cell with simpler fabricating process. The DSSC have a few advantages compared to past generation solar cell such as simple to fabricate, inexpensive materials, good power efficiency, and the material used are easily obtained [3]. Since the year 1991, DSSC shows a hike in popular among researchers and more attention were given to it as one of the most promising energy harvesting devices since the introduction of ruthenium based photosensitizers by O'Regan and Grätzel is being reported [4]. Michael Gratzel and his team at their private laboratory managed to comes out with "Gratzel Cell" or which also named as DSSC that functions that replicates the process of photosynthesis via the sensitization of a nanocrystalline $TiO_2$ film based on novel Ru bipyridl complex dye. In the study, results have shown high photoelectric conversion efficiencies of over 11%. [5-6].

Therefore, the DSSC have been studied with full attention as a promising alternative of a new solar cell which made up of porous metal oxide semiconductor electrode usually $TiO_2$ film capable of good absorption of dye, dye sensitizer, a counter electrode and redox electrolyte containing iodide/triiodide (I-/I3-). DSSC are capable of producing photosensitization on the wide band-gap metal oxide semiconductor, which means it converts visible light directly to electricity [3-4]. The dye molecules absorb a part of the visible light spectrum in sensitization process [7].

To achieve higher improvement in DSSC performance and decrease its costs of fabrication, natural organic materials are being study to improve the cell efficiency, decrease the production cost and might as well enhance cell durability [8]. Among the components of DSSC fabrication, semiconductor electrode is the most crucial one, in the form of titanium $TiO_2$. Due to its behavior that is mesoporous nanocrystalline, $TiO_2$ have wide surface area for the dye to be absorbed, $TiO_2$ has been widely implemented in DSSC. Based on past research, $TiO_2$ are more simple to fabricate, relatively cost saving and contributes to a better performance of DSSC [7-9]. Besides that, the design of organic dyes that is photo-sensitive are carefully done to achieve better conversion of light to electrical energy. This natural organic dye can be provided easily, require simple preparation, less costly, non-toxic and environmental friendly [10]. By thinking about the best condition for every parameter, the led explore is on the multilayer $TiO_2$ photoanode. The power produced of a DSSC is relying upon conduct of the photoanode. Consequently, the basic properties of $TiO_2$ films and its morphological properties are the essential variables for the photocatalyst and should be checked in detail.

## 1.2 Problem Statement

In this new generation, solar cell is the best possible alternatives for electrical energy resource due to its nature that is renewable and easily produce. Unfortunately, the first generation solar cell requires much higher cost of production while the second generation solar cell contains high toxicity (cadmium) contain in its materials used in fabrication. Due to these drawbacks in previous generations of solar cell, DSSC have emerged to become the best possible solutions for solar cell technologies. Although the DSSC are more cost-saving and easier to fabricate, the measurement power efficiency is important in determining the solar cell performance and sustainability. Based on previous research, the DSSCs have lower power efficiencies if contrast to most other types of solar cells in the global market. In 2015, a huge breakthrough in cell efficiency holding a record of 14.30% efficiency by a DSSC with the employment of non-metal organic dyes and triiodide based redox electrolyte [11]. However, Silicon (Si) based solar cell have the highest cell efficiency (up to 24.7%) if compared to other types of solar cells based on lab test [4]. Therefore, intensive studies are going on by researchers to improve the cell efficiency of

DSSCs by focusing on the improvement in semiconductor photoelectrodes, the material used as electrolyte, and the effect of organic dye materials.

Furthermore, the key elements that strongly influence the cell efficiency of DSSC namely the metal oxide semiconductor, counter electrode, glass substrate, photo sensitized dye and electrolyte. The focus is on the dye materials for photosensitization. It can be classified into two types that are non-organic and organic dye. Non-organic dye such as Ruthenium complexes are capable of achieving higher efficiency and more durable, there have been widely used in DSSC fabrication [12]. However, these non-organic dyes need higher cost for the material used and they are also regarded as highly toxic and carcinogenic. These matter have risen the awareness among researchers, and the studies of environmental-friendly dyes are going on intensively. Therefore, to outplay these problems, natural pigments are being used as sensitizing dye that is fully organic. The natural organic dye is not harmful to the environment, biodegradable and does not pollute the environment as it is disposed. In DSSC, the natural pigments such as anthocyanin that is extracted from fruits and vegetables are applicable of achieving high power efficiency. Thus, further research in organic dyes need to be done carefully to achieve better performance of DSSC.

Moreover, there different sort of wide bandgap semiconductor materials has been actualized in photoanode for DSSC creation. The materials utilized are Zinc Oxide (ZnO), Tin Dioxide ($SnO_2$) and Niobium Oxide ($Nb_2O_5$), which can just accomplish low power efficiency that is underneath 10-14% [13]. As of late, $TiO_2$ has pulled in consideration from specialists everywhere throughout the world because of its potential applications in ecological neighborly and age of vitality [6]. $TiO_2$ has been generally applied in fabrication of DSSC because of its nanocrystalline mesoporous structure that provides wide surface area for dye injection. Besides that, the energy conversion efficiency accomplished isn't that high, and the method of preparing the $TiO_2$ films are confounded and require cautious study dependent on different parameters. Therefore, this experiment is being conducted to study the effect of different synthesizing temperature as a critical parameter in preparing $TiO_2$ solution. These parameters are critical for improvement in the study of structural, optical and electrical properties in DSSC that can enhanced higher cell productivity and better efficiency.

## 1.3 Objectives of Study

The improvement in study of DSSC are done intensively over the years to achieve better understanding on the properties of the solar PV to enhance the electrical properties that leads to higher efficiency in solar-to-electricity conversion. This research is more towards the fabrication and characterization of $TiO_2$ on the Fluorine-doped $SnO_2$ conducting glass (FTO) and counter electrode for the dye sensitized solar cells. The objectives of this experiment are as follows:

- To fabricate a low-cost $TiO_2$ based DSSC.
- To investigate the structural and optical properties of $TiO_2$ with different synthesizing temperature of $TiO_2$ solution as a parameter.
- To investigate the electrical properties of $TiO_2$ based DSSC prepared with organic dye sensitizer.

## 1.4 Scope of Research

For this thesis, the optimization of solar-to-electric conversion efficiency are described using $TiO_2$ photoanodes based on DSSC. The synthesize of $TiO_2$ as photoanodes is done by the process of mixing-grounding the Titanium isopropoxide (TTIP) with acetic acid, distilled water, acetylacetone and polyethylene glycol (PEG) by using sol-gel method. For the conductive glass, Fluorine Tin Oxide (FTO) will be used and graphite material for the counter electrodes for the DSSC. The synthesizing temperature in preparing $TiO_2$ solution via sol-gel method will be the parameters in this experiment to enhance the electrical properties of DSSC. Therefore, analysis of structural and optical properties is done to carefully monitor the behavior of $TiO_2$ in the development of photoelectrodes for DSSC.

## 1.5 Project Outlines

In this thesis, there are 5 chapters to be revealed towards the end of this report including the introduction of DSSC and the equipment's and materials used in the project.

Chapter 1:

A brief introduction of the global issue regarding the non-renewable energy sources. The aim of the project is to overcome the issues in the problem statement. The scope of research will be explained in detail overall outcomes of research.

Chapter 2:

In this chapter, the fundamentals of the solar cells will be described and also the history related to the DSSC may be explained as well. In addition, the feasibility study that related with the project also been explained in the chapter.

Chapter 3:

This chapter discuss about the procedure and method used in the project. All of the equipment and the materials are explained in this chapter. Hence, the procedures to fabricate the DSSC and synthesize of $TiO_2$ and organic dye solution also included.

Chapter 4:

After the fabrication process done, the result and discussion along with the analysis will be described and explained in this chapter. Furthermore, the structural, optical and electrical properties are obtained via laboratory test and discussed for its surface morphology, absorption spectrum and I-V characteristics.

Chapter 5:

In this last chapter, the conclusion of all fabrication process and the characterization of $TiO_2$. Lastly, the outcomes of the experiment will explain the structural and the morphology properties of the $TiO_2$ film. Nevertheless, the recommendations also been described in the chapter.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview of DSSC studies

This chapter will explain about the background of DSSC and its principle of operation as well as the components used in fabrication of the compact layers in DSSC. Furthermore, the key components employed in the DSSC such as the metal oxide semiconductor (MOS), dye sensitizer, redox electrolyte and counter electrode are all being explained in details. All the components stated are very important as they influenced the performance and conversion efficiency of the DSSC.

## 2.2 History of Solar Cells

In today's world, energy is the basic needs for all mankind on Earth. The increase in global population resulting in higher demand of the amount of energy resource. However, the traditional main energy source that is fossil fuel was not enough to satisfy the increasing needs, in the same time, pollute the environment. Fossil fuel combustion leaves bad effects to the surrounding environment such as air pollution, water pollution, the Greenhouse Effect and also changed in global climate. Therefore, the introduction of solar energy, in the form of photovoltaic cell has become a most promising alternative energy source because of its environmental-friendly nature.

Solar cell converts the power of light into electricity directly using photovoltaic effect. The first discovery on photovoltaic effect was made by French physicist A. E. Becquerel at 1839 [14]. However, the development and commercialization of solar cells are limited for quite a long time due to its lower efficiency [15]. In 1954, the first usable solar cell was built by silicon at Bell Laboratories [16]. In solar cell components, a special