UNIVERSITI PUTRA MALAYSIA

TiO2 PHOTOANODE FOR TRANSPARENT DYE SENSITISED SOLAR CELLS

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TiO_2 PHOTOANODE FOR TRANSPARENT DYE SENSITISED SOLAR CELLS

By

ALAA A F HUSAIN

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

July 2018

DEDICATION

This thesis is especially dedicated to:

My Dear Father Ahmed Husain and my beloved mother Suhyla Husain,

My Dearest Husband Hadi Hani Juneidi,

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of science

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July 2018

Chair: Assoc. Prof. Wan Zuha Wan Hasan, PhD
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The Photovoltaic (PV) cell is the main component used to transfer photons directly into electricity. Traditionally PV technologies were categorized as mono-crystalline, poly-crystalline and amorphous, which can use a myriad of inorganic semiconductor materials, the most common being silicon. The economic drive to make solar cells more cost effective and efficient has driven developments with many different deposition technologies including dipping, plating, thick film and thin film. However today a new Organic PV technology is emerging giving rise to new interesting developments. The challenge of the current Photovoltaic is the big space it utilize to install solar panels system to support building or and application. This space is not available specially in the city where so many applications requires solar energy.

This research is interested in the new generation of solar cells and specifically Transparent Photo-Voltaic cells (TPV). Transparent solar cells can better utilize space and provide power by absorbing and utilizing unwanted light energy from windows in buildings and automobiles. TPV will make use of existing glass-covered areas to generate electricity leading to a better use of architectural space. There are several TPV technologies being researched using different materials and processes, which aim to achieve a high transparency and high electrical performance. However, few of these technologies reached the market and most of the researches are working on developing and improving this application. This research looks at the different technologies and compares, methods and materials used from a performance, aesthetic and financial perspective.

In this project the main focus is on the photoanode of Dye Sensitized Solar Cell (DSSC) to be transparent. Through using 3 types of deposition (screen printing, spin coating, Electrophoretic technique) and different structure of TiO_2 (nanotubes, transparent paste) the transparency to efficiency ratio can be controlled. Titanium dioxide is used as a photoanode with different structure and a selected dye with high average transmission in the visible region. The total average transparency achieved is 75% in the visible region and the efficiency is 3.2% using solar cell simulator.

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

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Oleh

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Sel fotovoltaik (PV) adalah komponen utama yang digunakan untuk Menukarkan foton secara terus kepada elektrik. Secara tradisional, teknologi PV dikategorikan sebagai mono-kristal, poli-kristal dan amorfus, yang boleh menggunakan pelbagai bahan semikonduktor bukan organik, kebiasaanya adalah silikon. Pemacuan ekonomi dalam menghasilkan sel suria yang lebih jimat dan cekap telah mendorong perkembangan dalam teknologi pemendapan yang berbeza termasuk pencelupan, penyaduran, filem tebal dan filem nipis. Walau bagaimanapun, teknologi PV Organik yang baru digunakan membawa kepada perkembangan yang menarik. Cabaran Photovoltaic semasa adalah ruang besar yang digunakan untuk memasang sistem panel solar untuk menyokong bangunan atau, dan aplikasi. Ruang yang besar dan luas ini tidak boleh didapati khasnya di bandar di mana terlalu banyak aplikasi yang memerlukan tenaga solar.

Penyelidikan ini menyasarkan ke arah sel solar generasi baru dan khususnya sel fotovoltaik lutsinar (TPV). Sel suria lutsinar boleh menggunakan ruang yang lebih baik dan memberi kuasa dengan menyerap dan menggunakan tenaga cahaya yang tidak diingini dari tingkap bangunan dan kereta. TPV akan menggunakan kawasan kaca yang sedia ada untuk menghasilkan elektrik yang membawa kepada ruang seni bina yang lebih baik. Terdapat beberapa teknologi TPV yang sedang dikaji menggunakan bahan dan proses yang berbeza, ia bertujuan untuk mencapai ketelusan dan prestasi elektrikal yang tinggi. Penyelidikan ini melihat pada teknologi yang berbeza dan membandingkan, kaedah dan bahan yang digunakan dari perspektif prestasi, estetik dan kewangan.

Dalam projek ini, tumpuan utama adalah pada foto anod Sel die sensitif Solar untuk menjadi telus melalui penggunaan tiga jenis pemendapan (percetakan skrin, lapisan spin, teknik elektroforetik) dan struktur titanium dioksida (TiO_2) yang berbeza (tiub nano, pes telus) lutsinar ke nisbah kecekapan yang boleh dikawal. TiO_2 digunakan sebagai foto anod dengan struktur yang berbeza dan pemilihan warna yang mempunyai penghantaran purata yang tinggi di rantau penglihatan. Jumlah lutisnar purata yang dicapai adalah 75% di rantau penglihatan dan kecekapannya adalah 3% menggunakan simulator sel solar.

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

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LIST OF ABBREVIATIONS

PV	Photovoltaic
TDSSC	Transparent Dye Sensitized Solar Cells
BIPV	Building Integration Photovoltaic
DSSC	Dye-Sensitized Solar Cells
TPV	Transparent Photovoltaic
E_{gap}	Energy Gap
CdTe	Cadmium Telluride
CdS	Cadmium Sulphide
TiO2	Titanium Dioxide
ZnO	Zinc Oxide
SnO2	Tin Dioxide
Nb2O5	Niobium Pentoxide
CE	Counter Electrode
TCO	Transparent Conducting Oxide
FTO	Fluorin-Doped Tin Oxide
NIR	Near- Infrared
Pt	Platinum
ITO	Idium-Doped Tin Oxide
TSC	Transparent Solar Cell
CBD	Chemical Bath Deposition
PVD	Physical Vapour Deposition
PLD	Pulsed Laser Deposition
ALD	Atomic Layer Deposition
EPD	Electrophoretic Deposition
OPV	Organic PV
ClAlPc	Chloro-Aluminium Phthalocyanine
BCP	Bathocuproine
DBR	Distributed Bragg Reflector
BBAR	Broadband Antireflection
TLSC	Transparent Luminescent Solar Concentrator
PSC	Polymer Solar Cell
AgNWs	Silver Nanowires
BHJ	Bulk-Heterojunction
QD	Quantum Dot
AVT	Average Transmission
SCQDSCs	Semi-Transparent Solar Cell

ETL	Electron Transporting Layer
HTL	Hole Transporting Layer
LiF	Lithium Fuoride
AR	Anti-Reflective
PANI	Polyaniline
CV	Cyclic Voltammetry
IPCE	Incident Photon-To-Current Conversion Efficiency
IPA	Isopropyl Alcohol
NT-TiO_2	Titanium Dioxide Nanotubes
DI	Deionized
IV	Hydrogen Hexachloroplatinate

CHAPTER 1

INTRODUCTION

1.1 Background

In recent years, there have been rapid increases in the development rate of new personal electronic devices, in the growth in demand for these devices, and in the growth in world population. These three factors have conspired to greatly increase energy demands, by as much as 60% in developed countries. Due to the pollution caused by fossil fuels, renewable and environmentally friendly energy sources are in the highest demand. The greatest potential for renewable energy comes from the sun. Today, more than 100 countries use the sun as a source of energy. Malaysia is one of these countries using solar energy, due to the availability of abundant sunlight throughout the year. The energy that can be obtained from the sun that falls on the surface of the earth in one day is at a rate of 120 PW, (1 PW = 1015 watt), which is more than enough to cover the energy required for the whole earth for 20 years [1].

Solar energy has many favourable characteristics that make it a good alternative to fossil fuel and it has the ability to fulfil the energy demands described previously. The distinctive characteristics of solar energy are associated with the fact that, it is a renewable source, available throughout most of the year, friendly to the environment (non-toxic and noiseless), requires minimal maintenance and space, lasts for a long time (25 years or more), is recyclable, is of low complexity, flexible in shape and has broad applications.

There are a variety of methods for converting solar energy into other forms of energy, such as heat, light, cooling, and electricity. The focus of this research is specifically for converting solar energy into electricity.

The thermal method is used to convert solar power into electricity. The thermal method uses reflectors to concentrate sunlight, generating a high temperature that produces high-pressure liquid that in turn rotates turbines to produce electricity. Another method to convert solar energy is to use photovoltaic (PV) systems that convert the solar light energy directly into usable electrical power [2]. A photovoltaic cell contains semiconductor materials that convert light into electricity and cause its flow through the cell to generate current. The higher the sun intensity, the more the cell produces power. The photovoltaic cell combines photo anode and counter electrode as the major components of solar cell, this research focus on the photoanode [3].

This research focus on transparent photovoltaic, specifically transparent photoanode used for implementing a transparent PV. The research goes through most of the published results on transparent solar cell and studies the best method to fabricate a transparent photoanode. Three methods are selected in this project, including screen printing, spin coating, and electrophoretic EPD. After testing the best method the other component of the solar cell is chosen carefully to meet the characteristic of transparent PV. The best dye and supporting layer with photoanode is selected and combined together in DSSC design. All samples prepared are tested for transmission and electrical characteristic. Best results are selected to be the candidate for transparent solar cell use.

1.2 Problem statement

Demand for energy is rapidly increasing worldwide. Energy from the sun is available to everyone and solar energy could be a good solution to fulfil this demand. Furthermore, most energy applications contain a good quantity of glass, such as buildings and automobiles with vast window surfaces. Ideally, solar devices would be integrated into these structures in order to obtain maximum coverage of solar energy.

One of the main challenges of current PV is the large space it requires to implement the solar system to support the applications [1]. It is not possible to apply this to large buildings and in a crowded city that dose not have empty space yet consume a lot of energy [4]. Transparency is a main property of glass that is not shared with currently commercialised solar cells. This creates a problem since the transparent glass in most applications is necessary to provide light to users within. It is highly desirable to transfer the transparency property to solar cells. Most previous research focus on high efficiency regardless of the effect on transparency. Currently there are few commercialized solar cells that achieved not more than 60% transmission using inorganic materials. On the other hand, most reported result focused on achieving high efficiency with some transmission using TiO_2. Previous research has a gap between transparency and efficiency [1-2].

The existing DSSC utilizing screen printing method has good efficiency of 9.2%, but the transparency is only 60%, which is not applicable for certain applications such as cars front windows which require at least 70% [2]. Therefor, this research focuses on building a transparent photoanode in order to make a transparent solar cell and to optimize a transparency of 70% with a reasonable efficiency using optimized 3 cm^2 DSSC design, which can be the main unit to build a transparent panel in the future that can be used in Cars front and side windows also in buildings. [5] Using FTO glass as an ideal sample that can represent the effect of other architectural glass. FTO is suitable with TiO_2 coating to be integrated into the glass production line, and high volume manufacturing [3].

1.3 Significance of the research and contribution

The research will build a transparent solar cell that can be used as a transparent solar panel suitable for all electrical and mechanical applications as well as buildings. Transparent dye sensitized solar cells (TDSSC) are suitable devices for most applications in Malaysia. The climate in Malaysia provides sun for more than 8 hours daily during the whole year. This makes solar cells a great green solution to cover the shortage in energy. There are so many applications for transparent DSSC in Malaysia such as building integrated photovoltaic (BIPV), cars, trains, and electronic devices. By replacing the glass with TDSSC, space and energy can be saved simultaneously.

The research focus on increasing the transparency of the photoanode to be used for building transparent solar cell and test all factors affect that with a careful selection of the best dye to be used with the transparent solar cell.

1.4 Research Objectives

The overall objective of this research is to produce a transparent solar cell, while the specific objectives are:

1. To characterize the physical properties and chemical constituents of transparent TiO_2 paste for transparent photoanode.

2. To optimize the factors leading to increase the solar cells' efficiency of more than 3% and TiO_2 photoanode transparency to more than 70%.

3. To propose an optimized structure for TDSSC that contain multi-layer of photo anode and selected type of dye.

1.5 Scope of the research

In this study, a laboratory-scale solar cell was fabricated using FTO glass as a substrate with a size of 1x1 cm^2 for experimenting and optimizing the transparency to efficiency ratio In room temperature (25 ^oC) [5]. It is preferable to test the solar cell with a smaller size not more than 1 cm^2 to obtain the maximum efficiency and eliminate the dependence of the solar cell area which might increase the electron loss and recombination. FTO glass has good resistance and a transparency above 84%, which make it good for transparent solar cell. It has not been tested for different weather conditions or under direct sunlight.[4] The only material used is TiO_2, due to the fact that it is organic, abundant source can be used as a semiconductor material. [2] TiO_2 structure was studied in a nano size range while the thickness of the film was studied over the range of a few microns. The only phase of TiO_2 is anatase.

1.6 Thesis organization

Five chapters are included in this thesis. Chapter one includes the background, objectives, problem statement, and scope of the research. Chapter two shows the literature review that summarizes all references cited in this research. Next, the experimental methods in chapter three and results in chapter four are discussed. Finally, chapter five includes the conclusions and recommendations based on the experimental observations.

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