Faculty of Engineering

FABRICATION OF AN ACTIVE LAYER OF ORGANIC SOLAR CELL (OSC) BY USING SPRAY COATING

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FABRICATION OF AN ACTIVE LAYER OF ORGANIC SOLAR CELL (OSC) BY USING SPRAY COATING

KHAIRUNISA BINTI KAMARUDIN

A dissertation submitted in partial fulfilment

of the requirement for the degree of

Bachelor of Engineering with Honours

(Mechanical and Manufacturing Engineering)

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I would like to dedicate this thesis to my beloved family and friends for giving me support and strength.

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ABSTRACT

Organic solar cell (OSC) is a renewable energy device that used to convert sunlight into electrical energy. OSC consists of single layer, bilayer and bulk-heterojunction structures. Bulk-heterojunction structure consists of anode electrode, hole transporting layer, active layer, electron transporting layer, cathode electrode and substrate. Nowadays, OSC has a lot of demand because of its production is cheaper than the inorganic solar cell where the spray coating method is introduced due to its ability to reduce waste of fluid quantity and low investment costs. Therefore, this study was conducted in order to observe the difference of surface morphology and thickness between spin and spray coating methods when an active layer of P3HT:PCBM in chlorobenzene was fabricated on the glass substrate. Apart from that, I also want to examine at which parameters of spray coating method are able to produce a film-thickness near to the thickness of the spin coating method. Therefore, the parameters included the distance between nozzle and glass substrate, number of spray times and pressure of airbrush have been taken into account. The data of thickness measurement for spin and spray coating methods was graphed with high-low lines in order to facilitate reporting of observational studies. Furthermore, the comparison between surface morphology of spin and spray coated samples have also been observed and studied by using the SEM and AFM images. The SEM and AFM are used to read across the surface of the samples and they are capable to sense the smallest variations on the surface of a material. However, the AFM can produce a greater level of detail for surfaces when compared to SEM. Based on the results of this study, the spray coating method is able to produce a film-thickness nearest to the thickness of spin coating at the parameters of 10 cm height, 8 spray times and airbrush pressure of 0.1 MPa. Besides, the spray coating method is also able to produce a smoother surface morphology than spin coating method.

ABSTRAK

Sel suria organik adalah alat tenaga yang boleh digunakan untuk menukar cahaya matahari kepada tenaga elektrik. Sel suria organik terdiri daripada beberapa struktur lapisan iaitu satu lapisan, dua lapisan dan sel suria hetero-simpang pukal. Struktur untuk sel suria hetero-simpang pukal terdiri daripada elektrod anod, lubang lapisan pengangkutan, lapisan aktif, elektron lapisan pengangkutan, katod elektrod dan substrat. Pada masa kini, sel solar organik mempunyai banyak permintaan kerana pengeluarannya adalah lebih murah daripada sel suria yang bukan organik. Dengan ini, teknik semburan endapan telah diperkenalkan kerana teknik tersebut mampu mengurangkan pembaziran kuantiti cecair dan juga kos pembuatan. Oleh itu, kajian ini dijalankan untuk melihat perbezaan antara permukaan morfologi dengan ketebalan lapisan aktif P3HT:PCBM dalam chlorobenzene yang telah disalut pada substrat kaca dengan menggunakan dua teknik iaitu putaran dan semburan endapan. Selain itu, saya juga mengkaji jenis-jenis parameter yang diperlukan untuk teknik semburan endapan supaya dapat menghasilkan ketebalan lapisan aktif yang berhampiran dengan ketebalan lapisan teknik putaran. Oleh itu, parameter yang diperlukan adalah jarak antara airbrush dengan substrat kaca, jumlah kali semburan dan tekanan udara airbrush telah diambil kira. Data untuk pengukuran ketebalan untuk teknik putaran dan teknik semburan endapan telah digunakan untuk menghasilkan graf. Selain itu, perbandingan di antara permukaan morfologi sampel hasil daripada teknik putaran dan teknik semburan endapan juga telah diperhatikan dan dikaji dengan menggunakan SEM dan AFM imej. SEM dan AFM telah digunakan untuk membaca seluruh permukaan sampel dan mereka mampu mengesan variasi kecil yang ada pada permukaan substrat kaca. Walau bagaimanapun, apabila dibandinkan dengan SEM, AFM boleh menghasilkan tahap imej yang lebih terperinci untuk permukaan morfologi. Berdasarkan hasil kajian ini, teknik semburan endapan mampu untuk menghasilkan sebuah ketebalan lapisan yang dekat dengan ketebalan teknik salutan putaran pada parameter 10 cm ketinggian, 8 kali semburan dan 0.1 Mpa tekanan udara airbrush. Selain itu, kaedah salutan semburan juga dapat menghasilkan permukaan morfologi yang lebih licin berbanding berputar kaedah salutan.

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°C	Degree Celsius
µm	Micrometre
cm	Centimetre
cm^2	Square Centimetre
eV	Electron Volt
mA	Miliampere
mg	Milligram
mL	Millilitre
MPa	Megapascal
nm	Nanometre
rpm	Revolutions per Minute
s	Second
V	Voltage
Wt. %	Weight Percentage

LIST OF ABBREVIATIONS

AFM	Atomic Force Microscopy
Ag	Silver
Al	Aluminium
AL	Active Layer
Au	Gold
BHJ	Bulk-Heterojunction
BIPV	Building Integrated Photovoltaics
Ca	Calcium
CdTe	Cadmium Telluride
CIGS	Copper Indium Gallium Selenide
Cu	Copper
D/A	Donor-Acceptor
DCB	Dichlorobenzene
DPE	Diphenylether
EQE	External Quantum Efficiency
ETL	Electron Transporting Layer
FF	Fill Factor
FTO	Fluorine-Doped Tin Oxide
HOMO	Highest Occupied Molecular Orbit
HTL	Hole Transporting Layer
ISC	Inorganic Solar Cell
ITO	Indium Tin Oxide

Lif	Lithium Floride
LUMO	Lowest Unoccupied Molecular Orbits
MEH-PPV	Poly[2-methoxy-5-(2'-ethyl-hexyloxy)-1,4-phenylene vinylene]
Mg	Magnesium
MoO_3	Molybdenum Trioxide
NaCl	Sodium Chloride
NiO	Nickel (II) Oxide
OSC	Organic Solar Cell
P3HT	Poly(3-hexylthiophene)
PBDTTT-C-T	Benzidithio-phene-thieno[3,4-b]thiophenecopolymer
PCBM	C60 derivative 6-phenyl-C61 butyric acid methyl ester
PCE	Power Conversion Efficiency
PDI	Perylenediimide
PPD-T2FBT	Poly[2,5-bis(2-hexyldecyloxy)phenylene)-alt-(5,6-difluoro-4,7-di(thiophen-2-yl)benzo[c][1,2,5] thiadiazole)]
PVC	Photovoltaic Cell
QE	Quantum Efficiency
SEM	Scanning Electron Microscopy
Si	Silicon
TiO_2	Titanium Dioxide
ZnO	Zinc Oxide

CHAPTER 1

INTRODUCTION

1.1 Background of Solar Cells

Solar cell is a simple semiconductor that also known as photovoltaic cell and used as a device to convert the light into electrical energy. The idea of solar cell is taken from leaf concept because they have something similar in converting the sunlight into chemical energy. The conversion of radiation energy into electricity is achieved by absorbing light and ionizing crystal atoms, thus it will produce free negatively charged electrons and positively charged ions (Bube & R.H., 1998). When the ionized state is mobile, the positive charged ions can be transferred from one atom to another atom where it acts as an electron and called as a hole. If the crystal's atom has absorbed sufficient lights energy, it will produce the electron-hole pair and based on Brownian motion, the electron and hole can move freely through the lattice. However, the electron-hole pair cannot move too far from each other and will recombine during Brownian motion. Furthermore, if electric field is generated during the motion, the electrons will be separated from the holes and move towards the anode, and the holes will move towards the cathode. Hence, the recombination will happen in the external circuit, thus the current will flow.

The first photovoltaic effect was first demonstrated in 1839 by using an electrochemical cell but known as photodiodes in this modern day. Seale (2003) stated Alexandre Edmond Becquerel was the first French physicist that discovered the photovoltaic effect which explains on how electricity can be generated from sunlight. He said that the light emitted on the electrode submerged in a conductive solution will create an electric current and voltage is produced. However, after much research on this has been done on this photovoltaic effect, the efficiency of photovoltaic power is very low and not economical for power generation but it can be used to measure lights. Over 100 years later, Russel Ohl is the first person who has developed the silicon solar cell in

1941. Based on the fact of silicon atom, four electrons in the outer shell is missing, therefore, it has poor conductor of electricity (Aldous, 2007). Nevertheless, the phosphorous atom has five electrons in the outer shell that can make it bond with silicon atoms. Hence, the energy can be generated in the process because the extra electron can be replaced by electromagnetic radiation.

However, it is impossible to capture the energy produce without creating any electric field. So, the efficiency of the solar cell can be improved by introducing impurities in the silicon material. In order to create the negative (N-type) and positive (P-type) semiconductors, the silicon must be mixed with phosphorous and boron atoms respectively. The electric field can be generated as the N-type and P-type layer are in contact with each other, thus the efficiency of solar cell are able to be achieved.

In 1954 at Bell labs, Chapin, Fuller and Pearson have demonstrated the ability of silicon solar cell and since then, the inorganic semiconductors development has grown (Goetzberger, Hebling & Schock, 2003). According to Bagher, Vahid & Mohsen (2015), solar cells can be categorized into three cells of generation which is first, second and third generation cells. First generation cell also known as conventional is made from crystalline silicon (Si) such as mono crystalline and multi crystalline Si. For the second generation cell, it is made up from thin-film solar cells that include amorphous Si, cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) cells. The third generation cell is a number of thin-film technologies that known as emerging photovoltaic because most of them have not been commercial yet and still under research for development phase.

Nowadays, the use of silicon is still dominating the technology in the photovoltaic solar cell's world market with power conversion efficiency (PCE) of 15-20% for mono-crystalline devices (Bagher, 2014).

1.2 Overview of Inorganic Solar Cell

The inorganic solar cell (ISC) also has a same function as organic solar cell (OSC) which is used to generate the electricity through the conversion of light energy. The ISC is made from inorganic semiconductor material and has a good efficiency when compared to an OSC (Chidichimo & Filippelli, 2010). The ISC uses inorganic semiconductor materials to create photovoltaic cells such as crystalline, multi crystal, amorphous, CdTe and CIGS (Miles, Zoppi & Forbes, 2007). Most photovoltaic cells are used in large-scale power generation such as centralized power stations and building integrated photovoltaics (BIPV). Many people are interested in BIPV because it can be used to generate power by adding the photovoltaic into the building envelope such as skylights, roof, walls, windows and more. Crystalline Si solar cell has been used for over half a century, but the development of solar cell has produced multi crystal Si, amorphous Si and CIGS with the energy band gap between 1.1-1.7 eV (Partain, 1995).

Furthermore, photovoltaic cell has been well-known for the past 50 years ago because it is used to supply power such as communications system, electronic gadgets, satellites and more. However, the ISC materials have lower absorptivity than organic materials and required thicker absorbing layers that lead to high costs (Bagher, 2014).

1.3 Overview of Organic Solar Cell

Nowadays, the world is becoming more polluted as there are many uses of non-renewable energy. Therefore, the OSC is introduced because it is one of the renewable energy that only required an energy source from the sun in order to operate. Therefore, many people are giving more attention on the research and the development of OSC.

According to Chidichimo & Filippelli (2010), OSC is made from semiconductor conjugated polymers material and the production technique is simple and only uses organic materials that are easy to be found because they are available in large quantities. To reduce production cost in packaging, import and export, the printing of functional layers from solution has been developed to the formation of the thin-film casting technology in order to produce a flexible organic electronics. Hence, the properties of OSC are light and flexible because the material is made from plastic.

The OSC is suitable for economical devices, but the efficiency is lower than ISC which proven in the chart of best research-cell efficiencies made by National Renewable Energy Laboratory. Based on Figure 1.1, the organic cell shows rapid enhancement of efficiency each year. Nevertheless, 11.5% of organic cell is still lower than 12.6% of inorganic cell. This is because due to its higher band gap and very sensitive to oxygen and humidity. Therefore, many research for the development of OSC has been done due to its rapid efficiency improvement, cost effective in energy harvesting, easy to process and compatible with flexible substrates. In addition, the structure of organic semiconductor is well-defined and the electronic transitions are quite narrows and have a tendency to be very susceptible to the background.

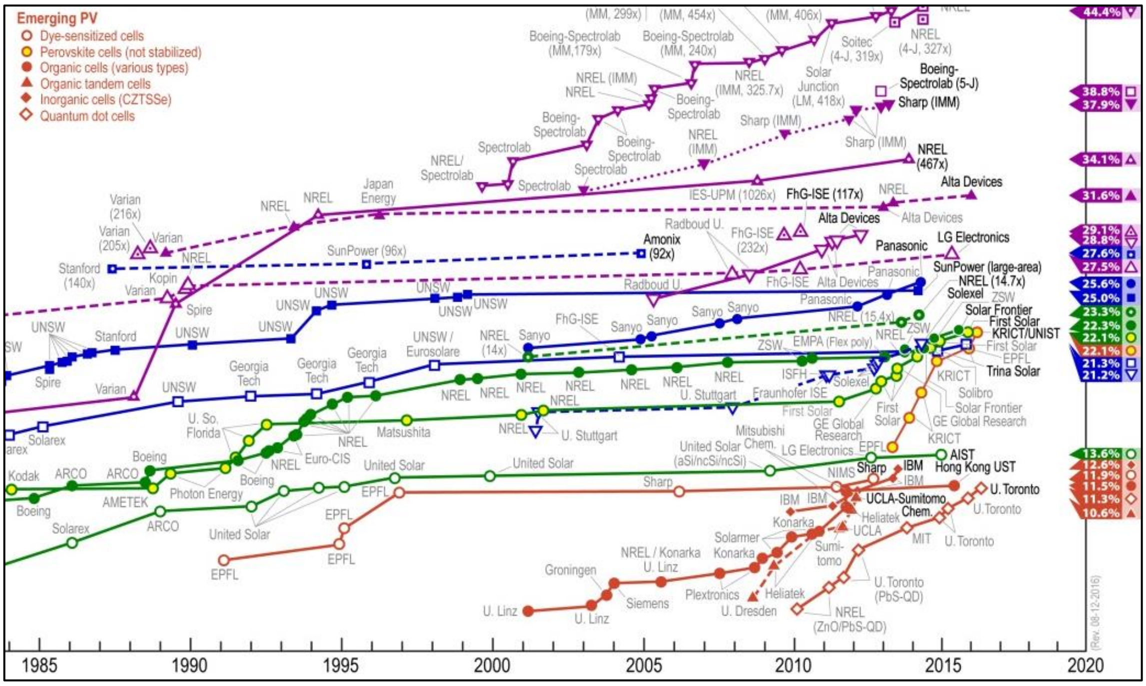

Figure 1.1: The development of organic solar cell's efficiency from 2001 until 2015. (Sources: National Renewable Energy Laboratory (NREL). Accessed on 1st October 2016)

1.4 Problem Statement

OSC has a lot of demand in this era because it is a renewable energy. Therefore, many studies have been done in order to improve photovoltaic performances and increase the PCE of OSC. Based on recent studies, various methods have been performed in which the choice of right methods and process parameters should be taken into account so that the high quality interfaces can be achieved. There are few methods that can be carried out in order to fabricate the OSC such as spin coating, doctor blading, slot-die coating, brush painting and spray coating.

The spin coating method is often used in fabricating the film layer of OSC because it is easy to use and low cost in manufacturing. However, in order to fabricate bulk-heterojunction OSC, this technique has major disadvantage because they required large amount of solution which can lead to high-priced facilities (Kim et al., 2013). For spin coating method, it is generally used in micro-fabrication and able to create thin-films with thickness below 10nm (Hanaor et al., 2011). But, lack of material usage efficiency is considered as a limitation to spin coating method because during the process, the material dispensed on the substrate is utilized for 2-5% only, while the remaining 95-98% is disposed (Tyona, 2013). As a substrate size demand increases nowadays, the large substrates cannot be spin at a sufficiently high rate in order to thin the film.

Therefore, spray coating method is introduced where it is able to reduce waste of fluid quantity and the investment costs (Colsmann et al., 2012). In practice, this process is done by using a spray airbrush and very small droplets can be deposited on the targeted substrate. During process, the kinetic energy that stored in each of the droplets produced will help them to spread on the substrate. Furthermore, this method is generally manipulated by liquid properties such as density, surface tension, viscosity, airbrush configuration and gas flow properties (Søndergaard, 2012). Even though the roughness of the device in spray coating method is rougher than spin coating method, but this method is able to produce higher quality OSC film due to its scalable criteria and mature process.

Hence, the main focus in this research is to compare the surface morphology of active layer that created on glass substrate and investigate the parameters involved when using both spray and spin coating methods. Therefore, it is essential to investigate and look into the details of parameters that can affect the performance of spray coating method such as number of spray, pressure and distance between the airbrush and targeted substrate. Apart from that, in order to have a nearest thickness to spin coating method, all the parameters of spray coating method will be investigated.

1.5 Aim

The aim of this research is to fabricate the active layer of OSC on the glass substrate at different parameters by using spray coating method.