INVESTIGATION OF FABRICATED TIPS-PENTACENE BASED ORGANIC DIODE USING SLIDE COATING DEPOSITION TECHNIQUE

FARA NAILA BINTI RUSNAN

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FARA NAILA BINTI RUSNAN
MK1221027T

(Tandatangan Pustakawan)

Tarikh : 26 Jun 2019

(Prof. Madya. Dr. Ismail Bin Saad)
Penyelia

DECLARATION

I hereby declare the material in this thesis is my own except for quotations, equations, summaries and references, which have been duly acknowledged.

29 AUGUST 2018

FARA NAILA BINTI RUSNAN

MK 1221027 T

CERTIFICATION

NAME : **FARA NAILA BINTI RUSNAN**

MATRIC NO. : **MK1221027T**

TITLE : **INVESTIGATION OF FABRICATED TIPS-PENTACENE BASED ORGANIC DIODE USING SLIDE COATING DEPOSITION TECHNIQUE**

DEGREE : **MASTER OF ENGINEERING (ELECTRICAL AND ELECTRONIC ENGINEERING)**

VIVA DATE : **28 FEBRUARY 2019**

CERTIFIED BY

1. SUPERVISORY COMMITTEE **SIGNATURE**

Associate Professor Dr. Ismail Saad 27/6/19

2. COMMITTEE MEMBER

Ir. Pungut Bin Ibrahim

Dr. Khairul Anuar Mohamad

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ABSTRACT

Organic material is one of the most capable material to fit into any kinds of substrates as it gained recent popularity for being able to be deposited under low maintenance of manufacturing. The performances are still comparable with non-organic based electronics. The main purpose of this study is to investigate fabricated TIPS-pentacene based organic diode using slide coating deposition technique. Different alignment of deposition method such as dip coating, spin coating and slide coating were compared and used drop casting deposition technique as benchmark. Slide coating has the ability to control the direction of deposition and the drying area as it will influence the quality of device. Optimum condition for depositing TIPS-pentacene were also taken into account where 60 minutes duration used to furnace, and 0.2 weight percentage needed to achieve highly oriented molecular properties. Molecular orientation of slide coated deposition technique has sharp (0 0 1) peak at 5.33° with FWHM of 0.32. This result is comparable with drop casting where 2θ angle is 5.27° and FWHM of 0.08. The measured I-V characteristics of the organic diode show rectifying behaviour and non-symmetrical graph, thus the junction is non-ohmic. Extraction of organic diode parameter such as current density, J, turn-on voltage, V_T, saturation current, I_0, barrier heights, φ_b, series resistance, R_s, and ideality factor, n, values at 1.33×10^{-7} A/cm^2, 2.22V, 19.32 A, 4.61×10^{-1}, $8.75 \times 10^6 \Omega$ and 18, respectively. Comparison research between chloroform and toluene solution to dilute TIPS-pentacene were also discussed in this study based on physical and electrical characterization, where toluene is the most suitable organic solvent to dilute TIPS-pentacene as it benefits more in both aspects compared to chloroform.

ABSTRAK

KAJIAN TENTANG ORGANIK DIOD YANG DIFABRIKASI BERASASKAN "TIPS-PENTACENE" MENGGUNAKAN TEKNIK PENYADURAN SECARA MENGGELONGSOR

Bahan organik adalah salah satu daripada bahan yang berkebolehan untuk digunakan dalam pelbagai jenis substrat. Kelebihan tersebut telah menarik perhatian apabila ianya boleh direnap dengan kadar kos penyengaraan pengilangan yang rendah. Prestasi yang diperolehi adalah setanding dengan peranti elektronik bukan organik. Tujuan utama kajian ini adalah untuk mengkaji tentang diod organik yang difabrikasi berasaskan " *TIPS-pentacene*" dengan menggunakan teknik penyalutan secara menggelongsor. Kajian tentang penjajaran bagi setiap teknik salutan; contohnya, penyalutan secara celupan, penyalutan secara putaran dan penyalutan secara menggelongsor, turut dijalankan. Perbandingan setiap penggunaan penjajaran dilakukan, dimana teknik penyalutan secara titisan digunakan sebagai tanda aras kajian. Teknik penyalutan secara menggelongsor mempunyai kelebihan untuk mengawal arah haluan pengenapan dan kawasan pengeringan, di mana faktor-faktor ini akan memberi kesan terhadap kualiti sesebuah peranti. Keadaan optimum bagi proses pengenapan " *TIPS-pentacene*" turut diambil kira dimana tempoh relauan adalah sepanjang 60 minit dan sejumlah 0.2 peratus berat kering digunakan bagi memperoleh sifat orientasi molekul yang baik. Orientasi molekul bagi Teknik pengenapan secara menggelongsor mempunyak puncak (0 0 1) yang tirus pada 5.33° bersamaan dengan lebar lengkap separa maksimum 0.32. Hasil yang diperoleh adalah setanding dengan teknik pengenapan secara menitis dimana sudut 2θ adalah 5.27° dan nilai lebar lengkap separa maksimum sebanyak 0.08. Pengukuran ciri-ciri arus dan voltan bagi diod organic menunjukkan tingkah laku berarus terus dan menghasilkan graf yang tidak simetri, sekaligus memberi gambaran sifat simpang bukan rintangan. Penyarian parameter diod organic seperti ketumpatan arus, J, voltan rangsangan, V_T, arus termendap, I_0, ketinggian samar, φ_b, rintangan bersisi, R_s dan faktor unggul, n, masing-masing memberikan nilai 1.33 x 10-7 A/cm2, 2.22V, 19.32A, 4.61X10-1, 8.75X106 dan 18. Perbandingan bahan pelarut bagi "TIPS-pentacene" antara kloroform dan toluene turut dibincangkan dalm kajian ini berdasarkan ciri-ciri fizikal dan elektrik, dimana toleuen adalah bahan pelarut yang paling sesuai kerana ia boleh memberi kelebihan dalam kedua-dua segi berbanding kloroform.

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LIST OF ABBREVIATIONS

TIPS-pentacene	3,16-bis(triisopropylsilylethynyl) pentacne
IV	current voltage
OLED	organic light-emitting diodes
OFET	organic field effect transistors
OSC	organic Schottky diode
RPM	rotation per minute
wt%	weight percentage
P3HT	Poly(3-hexylthiophene)
pBTTT	Poly(2,5-bis(3-alkylthiophen-2-yl)thienol (3,2-b)thiophene)s
C_{60}	Bulkminsterfullrene
$C_{18}H_{12}$	Tetracene
$C_{22}H_{14}$	Pentacene
TIPS-Ttriphenodioxazine	2,9-bis(triisopropysilylethynyl) triphenodioxazine
PMMA	Poly(methylmethacrylate)
OVPD	Organic vapor phase deposition
FWHM	Full width half maximum
XRD	X-ray diffraction
SEM	Scanning Electron Microscope
AFM	Atomic Force Microscope
ITO	Indium Tin Oxide
SE	Secondary Electron
BSE	Backscattered Electron
SMU	Source Meter Unit
RMS	Surface Roughness
2D	2-dimentional
3D	3-dimentional
MOM	Metal-organic-metal
HOMO	Highest occupied molecular orbital

LIST OF SYMBOLS

°	Degree
C	Celsius
J	Current density
V_T	Turn-on Voltage
I_0	Saturation Current
ϕ_b	Barrier Heights
R_S	Sheet Resistance
n	Ideality factor
B	Full width half maximum
Λ	Wavelength
V	Biased voltage
q	Electronic charge
k	Boltzmann's constant
T	Absolute temperature
A	Effective area of diode
A'	Richardson's constant

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CHAPTER 1

INTRODUCTION

1.1 Background

The application of organic semiconductor has seized different types of devices such as organic light-emitting diodes (OLED), organic field effect transistors (OFET) and organic Schottky diodes (OSD). Conventional inorganic material-based devices are stable but not as variety in terms of presentation. Today's gadgets require it to be fancy but efficient to keep up with the latest design. Therefore, organic materials are a good option as it can be fabricated onto solid nor flexible surfaces that will result in a more futuristic presentation towards the electronic devices.

6, 13 bis-triisopropylsilylethynyl (pentacene) (TIPS-Pentacene) commonly used as an organic material for semiconductor layer as it values high measured mobility values 0.401 cm^2/Vs for drop casted deposition technique and thermally annealed (Bae *et al.,* 2010). This is due to the existing side chains in TIPS-pentacene that helps to increase solubility in organic solvents (Bae *et al.*, 2010; Chen *et al.*, 2008). The presence of bulky groups also assisted the face-to-edge herringbone packing pattern to form stacking between all planes (Chen *et al.* 2008).

1.2 Problem Statement

This research is on slide coating as deposition methods for small molecule organic semiconductor, understanding its optimum condition to achieve highly oriented molecular properties. Comparable to other deposition method such as drop casting, the films formed are adequate for it to be fabricated into a device; the ability to control directions of solution drying area will be more helpful as it influences the electrical performance of one device. Therefore, slide coating techniques can control formation of thin film microsphere and produces high quality colloidal crystals.

1.3 Research Objective

The aim of this research is to fabricate a TIPS-pentacene based organic semiconductor diode. The objectives in accomplishing this project is highlighted as follow:

(i) To characterize and compare various techniques for TIPS-pentacene deposition thin film.

(ii) To analyse the physical properties and electrical characteristics of TIPS-pentacene thin film deposited using slide coating at different annealing time and solution concentration.

1.4 Research Scope

This research is to achieve the optimum parameter of depositing TIPS-pentacene with partial mechanical appliance for deposition source used. Partial here revenues as some of the deposition used such as drop casting, dip coating and slide coating were using non-mechanical method, whilst spin coating uses a mechanical deposition with selected rotation per minute (RPM). For dip coating deposition technique, the experiment was conducted near 90° and 180° angle for vertical and horizontal alignment, respectively. This is due to the limitation of apparatus to conduct it in a precise 90° and 180° angle, hence the non-mechanical method. Parameters involved in order to find optimum TIPS-pentacene deposition were different deposition techniques such as drop casting, dip coating, spin coating and slide coating. Optimum alignment for dip coating, spin coating and slide coating were evaluated. Furnace time and different weight percentage (wt%) for TIPS-pentacene deposition were also being measured.

For electrical characterization, different length for two different contacts, different choices of solvent and contact placement to measure current-voltage (I-V) performance based on TIPS-pentacene as semiconductor layer are also included in this research. The experiment conducted for TIPS-pentacene deposited was performed in a normal room temperature without any presence of clean room and vacuumed air chamber.

1.5 Thesis Outline

This research thesis consists of 5 chapters. Chapter 1 explains more on the introductory to organic semiconductor fields, problem statements, research objectives and scope were presented in this chapter.

Chapter 2 designates more on the core theories intricate to fabricate TIPS-pentacene based organic semiconductor diode. Fundamental concept such as identifying the morphologies and topographies of an ideal thin film is explained in this chapter. Basic theories on characterization using XRD, SEM, AFM, Surface profilometer and I-V measurement tools are included.

Detailed experimental steps on how to achieve ideal deposited thin films and organic semiconductor diode are explained in Chapter 3. Followed by the obtained results are presented and analysed in Chapter 4. Conclusion for this study and further suggestion or enhancement for this study is presented in the final chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Organic Semiconductors

For the past few decades, organic based electronics has gained attentions due to its capability of straight forward deposition techniques and low upkeeps, especially towards devices that requires large area coverage (Lee & Park, 2014; Choi *et al.*, 2012; Kim *et al.*, 2008). Organic based semiconductor has the capacity to compensate existing inorganic based semiconductor device, as inorganic fabrication techniques requires for it to be execute on high temperature and vacuum mode environment (Baklar, 2010; Lee & Park, 2014; Parry, 2013; Kim *et al.*, 2008; Saeed *et al.*, t.th.; Chung *et al.*, 2010). Generally, organic semiconductors are divided into two groups: micromolecular, which consists of sub-unit of small molecules semiconductors and oligomers; and other group, is macromolecular or also known as polymers. These groups are categorized according to the crystal stacking an its molecular orientation (Saeed *et al.*, t.th.).The significant contrast between both groups are the amount of molecular weight, where polymer has higher numbers of molecules (Baklar, 2010).

Both micro- and macromolecular organic materials can be shaped into solution form, which explains the straightforward deposition techniques and free from complex apparatus (Zhao, H. *et al*, 2015). Examples of deposition techniques available are drop casting, dip coating, spin coating and slide coating (Baklar, 2010; Lee & Park, 2014; Parry, 2013; Kim *et al.*, 2008; Akkerman *et al.*, 2012; Schols, 2011). One of the biggest concerns using organic material is the durability when it is bared to air and light, but alteration in the molecular structure of the organic material can overcome this problem (Baklar, 2010). The possibilities for organic based device are unlimited and were predicted to potentially replace the existing inorganic electronic production (Baklar, 2010; Parry, 2013).

2.2 Polymers

As explained in previous paragraph, the differences between a polymer and small- molecule organic materials are the structures, as the words poly- itself clearly disclose that polymer has longer structure (Baklar, 2010). Therefore, polymer are more malleable, have higher heat resistance and suitable for flexible based electronic devices (Baklar, 2010). Polymer's solubility ability were improved by adding side-chains to the structures, as most used conjugated structures for polymer semiconductors are poly(3-hexylthiophene) (P3HT) and latest technology findings like liquid-crystalline polymer known as poly(2,5-bis(3alkilthiophen-2-yl)thieno[3,2-b]thiophene) (pBTTT) as derivatives shown up to $1.0 cm^2V^{-1}s^{-1}$ mobility performance (Huang, 2009).

2.2.1 Poly(3-alylthiohene) (P3HT)

A regio-isomers can be formed depends on how the chains stacked; either head-to-tail, tail-to-tail or head-to-tail arrangements. Therefore, P3HT's polymer structures on how it is arranged based on region-isomer's variety will affects the performance of the electronic devices (Baklar, 2010). A P3HT is known to have good adhesiveness and mechanical properties that often used as reference to other compounds (Baklar, 2010). Despite the advantages, P3HT also experiences expiry when placed in open air (Baklar, 2010).

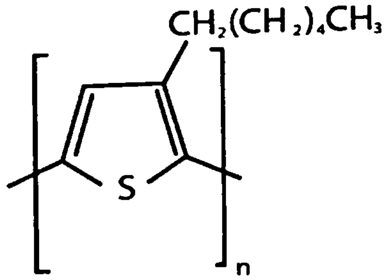

Figure 2.1: A poly(3-alkylthiophenes) chemical structure.

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