Electrical and Optical Properties of Triphenylamine-based Compounds and Devices

TONG Ka Lap

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy

Principal Supervisor: Dr. SO Shu Kong

Hong Kong Baptist University

Jun 2006
Abstract

Organic semiconductors receive much attention in the past decade in the world of electronics, especially in the display technology. They have many advantages, including flexibility, low cost, and ease of processing. The potential applications of organic semiconductors include organic thin film transistors (OTFTs), organic photovoltaic cells (OPCs), and organic light emitting diodes (OLEDs). In all applications, charge transport plays a crucial role on device performance. In general, transporting layer can be divided into electron transporting type and hole transporting type. The ideal candidate for electron transporter is still being searched. However, it is known that triphenylamine compounds can act as very useful hole transporters. For this class of materials, a thorough understanding and investigation are needed. In this project, different triphenylamine derivatives are investigated. Based on the time-of-flight (TOF) and admittance spectroscopy (AS) techniques, the charge transporting properties and the degree of dispersion of the materials will be measured; furthermore, applications of the triphenylamine derivatives in electroluminescence devices will also be examined.
### Table of Contents

Declaration ........................................................................................................................................... i
Abstract.................................................................................................................................................. ii
Acknowledgements ................................................................................................................................. iii
List of Tables ............................................................................................................................................... viii
List of Figures .......................................................................................................................................... ix

**Chapter 1**  Introduction to Organic Semiconductor ................................................................. 1
1.1 Characteristics of Organic Semiconductor ................................................................................. 1
1.2 Applications of Organic Semiconductor in Nowadays Technology .............................................. 4
  1.2.1 Organic Light Emitting Diode (OLED) .................................................................................. 4
  1.2.2 Organic Thin Film Transistor (OTFT) .................................................................................. 6
  1.2.3 Organic Photovoltaic Cell (OPV) .......................................................................................... 7
1.3 Research Focus ............................................................................................................................... 8

**Chapter 2**  Basic Principles ............................................................................................................ 9
2.1 Charge Conduction in Organic Semiconductor .............................................................................. 9
2.2 Charge Transport Mechanism .......................................................................................................... 10
  2.2.1 Hopping Conduction ............................................................................................................. 11
    2.2.1.1 Gaussian Disorder Model (GDM) ............................................................................... 11
    2.2.1.2 The Scher-Montroll Random Walk Model .............................................................. 14
    2.2.1.3 Concentration Dependence of Mobility ................................................................... 16
  2.3 Charge Injection Mechanism .......................................................................................................... 18
    2.3.1 Thermionic Emission ....................................................................................................... 18
    2.3.2 Tunneling Injection ....................................................................................................... 20
  2.4 Operating Mechanism of Organic Light Emitting Diodes (OLEDs) ............................................ 21
    2.4.1 Exciton ......................................................................................................................... 22
    2.4.2 Exciton Relaxation and Type of Light Emission .......................................................... 23
    2.4.3 Current-Voltage (IV) Characteristic of Typical OLEDs ............................................... 25
    2.4.4 OLEDs in Advanced Structure ...................................................................................... 27

**Chapter 3**  Experimental Techniques ............................................................................................. 28
3.1 Materials Purification ..................................................................................................................... 28
  3.1.1 Polymeric Material .............................................................................................................. 28
  3.1.2 Small Molecular Material ................................................................................................ 30
3.2 Sample Preparation ....................................................................................................................... 31
3.2.1 Substrate Treatment ................................................................. 31
3.2.2 Sample Fabrication ................................................................. 32
  3.2.2.1 Spin Coating .................................................................. 32
  3.2.2.2 Thermal Evaporation ..................................................... 36
3.2.3 Encapsulation of Sample ......................................................... 37
3.3 Characterization Techniques and Apparatus ......................... 38
  3.3.1 The Time-of-Flight (TOF) Method ....................................... 38
  3.3.2 Admittance Spectroscopy (AS) ............................................. 41
  3.3.3 Current-Voltage-Luminance (IVL) Measurement ................ 43
  3.3.4 Electroluminescence (EL) Measurement ............................ 44

Chapter 4 Transport and Luminescence in Hole Transporting Compounds. 45

4.1 Introduction to the Naphthyl Phenylamine (NPA) Hole Transporting
Model Compounds ........................................................................ 45
4.2 Effect of Dipole Moment ........................................................... 47
4.3 Results and Discussions ........................................................... 48
  4.3.1 The Hole Mobilities of the NPA Compounds ....................... 48
  4.3.2 The Dipole Moment Effect from Conducting Small Molecules .. 49
  4.3.3 The Dipole Moment Effect from Polymer Matrix .................. 52
  4.3.4 Luminescent Properties of the NPA Compounds .................. 55
4.4 Conclusion ................................................................................ 58

Chapter 5 Charge Mobilities of Bipolar Compounds and Their Application 59

5.1 Introduction to the XOT Compounds ........................................ 60
5.2 Results and Discussions ........................................................... 61
  5.2.1 Bipolar Carrier Transport Characteristic ............................. 61
  5.2.2 Application of XOT Compounds to OLEDs ....................... 66
  5.2.3 Current Efficiency Characteristic of the XOT Devices ......... 70
  5.2.4 The Role of Current Balance in OLEDs Efficiency ............... 70
  5.2.5 Current Balance Characteristic on the AOT Device ............ 73
5.3 Conclusion ................................................................................ 76

Chapter 6 Effects of Carrier Scattering and Trapping on Charge Transport 78

6.1 Introduction to the NPB Compounds and Other Involved Dopants .... 79
6.2 Concepts of Charge Trapping and Scattering ............................. 80
6.3 Results and Discussions ........................................................... 81
  6.3.1 Effects of Carrier Trapping and Scattering on Hole Mobility .. 81
  6.3.2 Effect of Impurities on Dispersivity of Organic Materials ...... 85