SIMULATION AND CHARACTERIZATION OF CHARGE CARRIER TRANSPORT IN ORGANIC SEMICONDUCTOR TRANSISTOR

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The completion of the thesis has been made possible by many other people, who have supported me throughout the project. Hence, I would also like to take this opportunity to record my appreciation to those who are directly and indirectly involved in writing this thesis.

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I would like to begin by thanking my father, Shuib Bin Dirwan, for his constant, unconditional love and support. For my late mother, Maznah Binti Abd Ghaffar, no words are sufficient to describe my late mother's contribution to my life. I owe every bit of my existence to her. This thesis is dedicated to her memory. I have been lucky to receive tremendous affection from several members in my extended family. Their support and encouragement has been instrumental in my overcoming several hurdles in life. Last but not least, my appreciation goes to each and every person who had encouraging me during my study.

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ABSTRACT

The main objective of this research is to investigate the charge transport in organic devices by simulating the 2-D design structure of the device using TCAD tools. As organic transistors are preparing to make improvements towards flexible and low cost electronics applications, an accurate models and simulation methods were demanded to predict the optimized performance and circuit design. The extraction and analysation of the transistor parameters from the electrical characterization of the 2-D organic semiconductor device were done to learn the behavior of the device itself. The characterization can describe the behavior of the transistor in the linear and saturation region, which is determining the drain current for any applied voltages. One of the important parameter for organic transistor devices is field effect mobility, the extraction of gate voltage dependence and the contact effects. Acknowledging the contact effect is very significant since it contribution on the device performance. Varied temperature research on organic transistor also has been used to characterize charge transport. There few common established model for charge transport in organic semiconductors because the exposed on thermally activated charge transport which is activation energies. Thus, the analysis of the effect of contact resistance and thermal activation energy of organic transistor also been investigated. The contact resistance obtained then fitted into the linear region equation for modified mobility, μ_{mod}, which obtain higher mobility than those obtained from the common linear region mobility model, proves that contact resistance should be considered while estimating the mobility. The observed temperature dependence of mobility can be explained by empirical MNR while there is an inverse relationship between E_a and μ_{MN}. The μ_0 reveals that lower temperature region has lower mobility than the higher temperature region.

ABSTRAK

SIMULASI DAN PENCIRIAN PENGANGKUTAN PEMBAWA CAS DALAM TRANSISTOR SEMIKONDUKTOR ORGANIK

Objektif utama kajian ini adalah untuk menyiasat angkutan cas dalam peranti organik oleh simulasi reka bentuk struktur 2-D peranti menggunakan alat-alat TCAD. Sejak akhir ini, transistor organik telah mengalami penambahbaikan ke arah aplikasi elektronik fleksibel dan kos rendah, mempunyai model yang tepat dan kaedah simulasi telah digunakan untuk meramalkan prestasi dan reka bentuk litar untuk dioptimumkan. Pengekstrakan dan analisis parameter transistor dari pencirian elektrikal di dalam 2-D peranti semikonduktor organik telah dijalankan untuk mengetahui bagaimana keputusan peranti itu sendiri. Pencirian boleh menggambarkan keadaan transistor di kawasan linear dan tepu, yang menentukan arus salir bagi mana-mana voltan digunakan. Salah satu parameter yang penting untuk peranti transistor organik adalah mobiliti efektif medan elektrik, pengekstrakan pada kerbergantungan voltan dan kesan kontak. Ia telah pon diakui bahawa kesan kontak mempunyai hubungan yang sangat ketara kepada prestasi peranti. Penyelidikan suhu pada pelbagai tahap untuk transistor organik juga telah digunakan untuk mencirikan pengangkutan caj. Terdapat beberapa model yang dihasilkan untuk pengangkutan caj dalam semikonduktor organik kerana terdedah kepada pengangkutan caj yang diaktifkan secara haba yang merupakan tenaga pengaktifan bagi sesuatu transistor tersebut. Oleh itu, analisis kesan rintangan kontak dan tenaga pengaktifan haba transistor organik juga telah disiasat. Rintangan kontak yang diperolehi telah diaplikasikan ke dalam persamaan kawasan linear untuk mobiliti yang diubah suai, μmod, yang mendapatkan mobiliti yang lebih tinggi berbanding yang diperolehi dari linear model mobiliti kawasan tepu yang sama, membuktikan bahawa rintangan kontak perlu dipertimbangkan semasa menganggarkan mobiliti. Pergantungan pada suhu juga diperhatikan pada mobiliti dapat dijelaskan oleh model MNR yang menunjukkan terdapat hubungan songsang antara E_a dan μ_{MN}. Pendapatan nilai μ_0 juga telah mendedahkan bahawa kawasan suhu yang lebih rendah mempunyai mobiliti lebih rendah daripada suhu yang lebih tinggi.

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LIST OF ABBREVIATIONS

OFETs	-	Organic field effect transistors
FETs	-	Field effect transistors
HOMO	-	Highest occupied molecular orbital
LUMO	-	Lowest unoccupied molecular orbital
PF	-	Poole-Frenkel
TOF	-	Time of flight
TCAD	-	Technology computer-aided design
OTFTs	-	Organic thin film transistors
ANN	-	Artificial neural network
TFT	-	Thin film transistor
MNR	-	Meyer-Neldel Rule
MTR	-	Multiple trapping and release
TLM	-	Transmission line method
MOSFET	-	Metal-oxide semiconductor field effect transistor
FinFET	-	Fin Field Effect Transistor
FDSOI	-	Fully depleted silicon on insulator
HEMTs	-	High-electron-mobility transistors
HBTs	-	Heterojunction bipolar transistors
GUI	-	Graphical user interface

LIST OF SYMBOLS

E_F	-	Fermi energy
E_{HOMO}	-	Energy of the band edge of semiconductor
E_{vac}	-	Vacuum energy level
ϕ_B	-	Schottky barrier of height
ϕ_M	-	Metal work function
V_D	-	Drain voltage
V_G	-	Gate voltage
V_{TH}	-	Threshold voltage
k_B	-	Boltzman constant
T	-	Temperature
W	-	Channel Width
L	-	Channel length
V_{DS}	-	Source drain voltage
I_{DS}	-	Drain source current
V_{GS}	-	Gate source voltage
C_i	-	Capacitance of the insulator
μ	-	Mobility
G	-	Ratio of current and voltage
σ	-	Material parameter conductivity
A	-	Area of the device
d	-	Length of the device
J	-	Drift current
μ_p	-	Diffusion mobility

D_p	-	Diffusion coefficient
μ_0	-	Zero-field mobility
γ	-	Poole-Frenkel fitting parameter
ε	-	Electric field
μ_i	-	Intrinsic mobility
Δ	-	Zero activation energy
T_{eff}	-	Effective temperature
T_0	-	Temperature fitting parameter
F	-	Magnitude of the electric field
$\mu(E)$	-	Field dependent mobility
β	-	Electron Poole-Frenkel factor
E	-	Electric field
R_C	-	Contact resistance
V_C	-	Contact region at the channel
T_{MN}	-	Isokinetic temperature
E_{MN}	-	Meyer-Neldel energy
E_a	-	Variable activation energy
μ_{MN}	-	Meyer-Neldel mobility
μ_{FE}	-	Field effect mobility
ε_i	-	Dielectric permittivity
d_i	-	Dielectric thickness
Q_o	-	Surface density
$Q_g(x)$	-	Surface density of the carriers in the accumulation layer
$V_s(x)$	-	Ohmic drop
$V(x)$	-	Potential on coordinate x

$W(x)$	-	Width of the depletion region
R_s	-	Parasitic source
R_d	-	Drain contact resistance
R_p	-	Parasitic resistance
R_{ch}	-	Channel resistance
μ_{linear}	-	Linear mobility
μ_{mod}	-	Modified contact resistance mobility

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CHAPTER 1

INTRODUCTION

1.1 Project Background

As the organic semiconductors were introduced on the early years of its discovery, the structure of organic semiconductor is proven compatible with thin film transistor (TFT) but have limitation on the organic material which have low mobility in device performances of initial device (Calvetti *et al.*, 2005). Many techniques were introduced to improve organic semiconductor performance especially on the charge-carrier mobility and pulling the interest of industrial group board into research programs on organic transistor (Li and Kosina, 2005). Even though the carrier mobility of organic materials makes their performance characteristics lag behind traditional inorganic semiconductors by a thousand times or more, the organic semiconductors offer easier low-temperature processing than silicon, resulting in lower cost semiconductors with highly tunable properties (Johnson, 2010).

As the interest getting bigger, the physical dimensions of organic semiconductor device were scaling down. For example, the channel length in organic thin film transistor is getting shorter, which can lead to substantial deviations of the device such as short channel effects (Li and Kosina, 2005). It is estimated that the carriers move at a much higher velocity and produced very high current (Brütting, 2006). Hence, an accurate extraction of certain type of organic transistor model parameters is benefits from modelling and circuit simulation and could be a give significantly higher performance value as it will be more reliable according to the specified configuration (Weis *et al.*, 2013).