

Device Architecture and Materials for Organic Light-Emitting Devices

Sarah Schols

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Targeting High Current Densities
and Control of the Triplet Concentration

 Springer

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Preface

This book is a reprint of the manuscript entitled “Device architecture and materials for organic light-emitting devices”, that was submitted to the jury deciding on the achievement of my PhD at the Katholieke Universiteit Leuven in Belgium. It is the result of five years fascinating research at imec in Leuven, Belgium, between 2004 and 2009. Different people contributed to my work and I want to show gratitude to all of them. First, I would like to thank my two promoters, Prof. Paul Heremans (KUL/imec) and Prof. Robert Mertens (KUL/imec) who gave me the opportunity to start a PhD in an inspiring environment as imec. I am also very grateful to the other PhD jury members who took the time to carefully read my manuscript: Prof. Mark van der Auweraer (KUL), Prof. Jan Engelen (KUL), Prof. Henning Sirringhaus (University of Cambridge), Prof. Uli Lemmer (Universität Karlsruhe) and Prof. Adhemar Bultheel (KUL). My special thanks go to Andrey Kadashchuk for introducing me into the exciting world of spectroscopy and for the many scientific discussions, but of course also all other colleagues of the Polymer and Molecular Electronics group at imec with whom I worked together during my PhD are gratefully acknowledged. Besides, I would like to thank Thilo Stöferle (IBM Research Zurich), Tobias Plötzing (RWTH Aachen) and Thorsten Wahlbrink (AMO GmbH) for the nice collaboration. The FWO is acknowledged for the financial support. Finally, I warmly thank my family for their continuous support and interest in my work.

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Contents

1	Introduction	1
1.1	Organic Semiconductors	1
1.1.1	Semiconducting Properties of Organic Materials	2
1.1.2	Charge Transport in Organic Materials	4
1.1.3	Optical Transitions in Organic Materials	6
1.2	State of the Art Organic Light-Emitting Devices	9
1.2.1	Organic Light-Emitting Diodes	9
1.2.2	Organic Light-Emitting Transistors	11
1.3	Organic Semiconductor Lasers	13
1.3.1	General Aspects of Laser Action	13
1.3.2	Motivation for Plastic Lasers	15
1.3.3	Lasing in Organic Semiconductors	17
1.3.4	Prospects for Electrically Pumped Organic Lasers	27
1.4	Outline	31
2	Materials and Experimental Techniques	33
2.1	Sample Fabrication	33
2.1.1	Materials Used in this Work	33
2.1.2	Deposition Techniques	34
2.1.3	Fabrication of Photonic Feedback Structures	37
2.2	Device Characterization	41
2.2.1	Transistor Measurement and Parameter Extraction	41
2.2.2	Characterization of OLEDs	42
2.2.3	Time-Resolved Photoluminescence Measurements	43
2.2.4	Time-Resolved Pump-Probe Experiments	45
2.2.5	Amplified Spontaneous Emission and Loss Measurements	46
2.2.6	Determination of Thermally Stimulated Luminescence	47
3	Organic Light-Emitting Diodes with Field-Effect Electron Transport	49
3.1	Device Fabrication	50
3.2	Device Operation	53
3.3	Device Performance	56

3.3.1	Optical and Electrical Characterization	56
3.3.2	Analysis	57
3.4	Improvement of the External Quantum Efficiency	60
3.5	Summary and Conclusions	62
4	Devices Based on Diperfluorohexyl-quaterthiophene Derivatives . .	65
4.1	Characterization of the Electron-Transporting Materials DFH-4T and DFHCO-4T	66
4.2	Devices Based on DFH-4T	69
4.2.1	Transistors Based on DFH-4T	69
4.2.2	DFH-4T in OLEDs with Field-Effect Electron Transport . .	70
4.3	Devices Based on DFHCO-4T	72
4.3.1	High Performance DFHCO-4T Transistors	72
4.3.2	DFHCO-4T in OLEDs with Field-Effect Electron Transport	76
4.4	Comparison	77
4.5	Summary and Conclusions	78
5	Control of the Triplet Concentration in Organic Light-Emitting Devices	81
5.1	Pulsed Excitation of OLEDs with Field-Effect Electron Transport .	82
5.1.1	Pulse-Width Dependence of Organic Light-Emitting Devices	82
5.1.2	Effects Influencing the Pulsed Excitation Behavior of OLEDs	83
5.2	Triplet Excitation Scavenging in Films of Conjugated Polymers . .	86
5.2.1	Triplet Scavenging in Liquid-State Organic Dye Lasers . .	86
5.2.2	Triplet Scavenging in Solid-State Organic Thin Films . . .	88
5.3	Summary and Conclusions	94
6	Triplet-Emitter Doped Organic Materials	97
6.1	Triplet Dynamics and Charge Carrier Trapping in Triplet-Emitter Doped Conjugated Polymers	97
6.1.1	Spectroscopic Characterization	99
6.1.2	Thermally Stimulated Luminescence in CNPPP Doped with Btp ₂ Ir(acac)	110
6.2	Optical Pumping of Triplet-Emitters	111
6.2.1	Attempts to Observe ASE Using Btp ₂ Ir(acac)	112
6.2.2	Attempts to Observe ASE Using F5Ph and GDP16b	113
6.3	Summary and Conclusions	114
7	Value of OLEDs with Field-Effect Electron Transport for Lasing Applications	117
7.1	Potential of OLEDs with Field-Effect Electron Transport as Laser Device Configuration	117
7.1.1	High Current Densities	118
7.1.2	Reduced Absorption Losses	119

7.2	Optically Pumped Lasing Experiments	123
7.2.1	Stimulated Emission in Alq ₃ :DCM ₂	124
7.2.2	Stimulated Emission in Stacks Comprising Alq ₃ :DCM ₂ . .	126
7.2.3	Discussion	131
7.3	Device with Integrated Field-Effect and Photonic Features	131
7.4	Summary and Conclusions	133
8	General Conclusions and Future Outlook	135
8.1	Overview of the Main Results	135
8.2	Suggestions for Further Research	137
	References	139

List of Symbols and Abbreviations

α	(Depending on context) 1. Loss coefficient (cm^{-1}) 2. Absorption coefficient (cm^{-1})
α_{photon}	Photon loss (cm^{-1})
$A(\lambda)$	Constant related to the cross-section for spontaneous emission
c	(Depending on context) 1. Concentration (wt%) 2. Speed of light in free space (299.79×10^6) (m/s)
C_{ox}	Gate dielectric capacitance per unit area (F/m^2)
δ	Density (g/cm^3)
ΔE_T	Difference in triplet energy (eV)
ΔG°	Gibbs free energy (kJ/mol)
Δr	Nuclear displacement ($\text{\AA}$)
ΔE_{ST}	Singlet-triplet splitting (eV)
$\varepsilon(\lambda)$	Absorption spectrum
ε_r	Relative dielectric constant
η_{ext}	External quantum efficiency (%)
η_{int}	Internal quantum efficiency (%)
η_{coupling}	Out-coupling efficiency (%)
E°	Standard cell potential (V)
E_{phot}	Average photon energy (eV)
F	Faraday constant (≈ 96485) ($\text{J}/(\text{V mol})$)
$f(\lambda)$	Photoluminescence spectrum
g	Gain coefficient (cm^{-1})
γ	Charge balance
Γ	Optical confinement factor (%)
h	Planck's constant ($\approx 6.626 \times 10^{-34}$) (Js)
I	(Depending on context) 1. Light intensity (W/cm^2) 2. Current (A)
I_{ds}	Drain to source current (A)
I_p	Pumping intensity (J/cm^2)
J	Current density (A/cm^2)

k_{ET}^F	Förster energy transfer rate (s^{-1})
k_{ET}^D	Dexter energy transfer rate (s^{-1})
K	Constant proportional to the orbital overlap between host and guest
κ	Polarization factor
l	Distance traveled in the gain medium (cm)
L	(Depending on context) 1. Sum of the van der Waals radii of host and guest (nm) 2. Transistor channel length (μm)
L_{diff}	Exciton diffusion length (nm)
λ	Wavelength (nm)
λ_{Bragg}	Bragg wavelength (nm)
λ_{exc}	Excitation wavelength (nm)
Λ	Modulation periodicity of a DFB resonator (nm)
m	DFB order number
M	Molecular weight (g/mol)
μ	Mobility (cm^2/Vs)
n	(Depending on context) 1. Index of refraction 2. Overall number of electrons exchanged between an oxidizing and reducing agent
n_{eff}	Effective refractive index
N_{exc}	Density of excited states (cm^{-3})
N_{th}	Exciton density at the laser threshold (cm^{-3})
N_A	Avogadro's constant ($\approx 6.022 \times 10^{23}$) (mol^{-1})
v_i	Vibrational energy level (eV)
p	Pressure (torr)
ϕ_{PL}	Absolute photoluminescence efficiency (%)
P_{meas}	Measured light power (W)
P_{tot}	Total optical power (W)
$\Psi_{molecule}$	Wavefunction of a molecule
$\Psi_{electronic}$	Electronic component of the molecular wavefunction
$\Psi_{nuclear}$	Nuclear component of the molecular wavefunction
q	Elementary charge ($\approx 1.602 \times 10^{-19}$) (C)
Q	Resonator quality factor
R	Mean distance between host and guest (nm)
R_0	Effective Förster radius (nm)
r_{st}	Singlet/triplet ratio of excitons
ρ	Average distance between dopant molecules (nm)
S_i	Singlet exciton energy level (eV)
S	Subthreshold slope (V/dec)
σ_{RZ}	Exciton density per unit area in the recombination zone (cm^{-2})
$\sigma_{SE}(\lambda)$	Cross-section for stimulated emission (cm^2)
σ_{TT}	Cross-section for triplet-triplet absorption (cm^2)
T_i	Triplet exciton energy level (eV)

T_{bake}	Baking temperature (°C)
t	Thickness of the dielectric layer (nm)
t_{del}	Time delay (s)
τ	Lifetime (s)
τ_r	Radiative lifetime (s)
V_{ds}	Drain to source voltage (V)
V_{gs}	Gate to source voltage (V)
V_{on}	Onset voltage (V)
V_{th}	Threshold voltage (V)
W	Transistor channel width (μm)
AFM	Atomic force microscopy
Ag	Silver
Al	Aluminum
Alq ₃	Tris-(8-hydroxyquinoline) aluminum
ASE	Amplified spontaneous emission
AZO	Aluminum doped zinc oxide
BARC	Bottom anti reflection coating
BCl ₃	Boron trichloride
BSP-Me	1,4-Bis(4-methylstyryl)benzene
Btp ₂ Ir(acac)	Bis(2-(2'benzothienyl)pyridinato-N,C ^{3'})(acetylacetonate)- iridium(III)
CAMFR	Cavity modelling framework
CCD	Charge coupled device
CH ₂	Methylene
CNPPP	2-[(6-cyano-6-methylheptyloxy)-1,4-phenylene] copolymer
COT	1,3,5,7-cyclooctatetraene
Cr	Chromium
CW	Continuous-wave
C ₄ F ₈	Octafluorocyclobutane
DBR	distributed Bragg reflector
DCM	4-(dicyanomethylene)-2-methyl-6-[(4-dimethylaninostyryl)- 4H-pyran
DCM ₂	4-(dicyanomethylene)-2-methyl-6-(julolindin-4-yl-vinyl)- 4H-pyran
DF	Delayed fluorescence
DFB	Distributed feedback
DFH-4T	α,ω -diperfluorohexyl-quaterthiophene
DFHCO-4T	5,5'''-diperfluorohexylcarbonyl-2,2':5',2'':5'',2'''-quaterthi- ophene
2D	Two-dimensional
DOS	Density of states
EBL	Electron beam lithography
EL	Electroluminescence
ETL	Electron-transporting layer
Fe	Iron

FWHM	Full-width-half-maximum
F ₁₆ CuPc	Copper hexadecafluorophthalocyanine
He	Helium
HOMO	Highest occupied molecular orbital
HSQ	Hydrogen silsesquioxane
HTL	Hole-transporting layer
H ₂ O	Water
IC	Internal conversion
ICP-RIE	Inductively coupled plasma reactive ion etching
IL	Interference lithography
ISC	Intersystem crossing
ITO	Indium tin oxide
LEOFET	Light-emitting organic field-effect transistor
LiF	Lithium fluoride
LPPP	Ladder-type poly(para-phenylene)
LUMO	Lowest unoccupied molecular orbital
MEH-PPV	Poly(2-methoxy-5-(2'-ethyl-hexyloxy)-1,4-phenylene-vinylene)
MeLPPP	Methyl-substituted ladder-type poly(para-phenylene)
Mg	Magnesium
MTR	Multiple trapping and release model
N ₂	Nitrogen
OLED	Organic light-emitting diode
OMA	Optical multichannel analyzer
OMBD	Organic molecular beam deposition
OTFT	Organic thin film transistor
O ₂	Oxygen
P α MS	Poly- α -methylstyrene
PF	Prompt fluorescence
PF2/6	Poly(9,9-di(ethylhexyl)fluorene)
Ph	Phosphorescence
PL	Photoluminescence
PMMA	Poly(methyl metacrylate)
PmPV-co-DOctOPV	Poly(<i>m</i> -phenylenevinylene- <i>co</i> -2,5-dioctoxy- <i>p</i> -phenylenevinylene)
PPV	Poly(phenylene vinylene)
PS	Polystyrene
PTAA	Poly(triarylamine)
PTCDA	3,4,9,10 perylenetetracarboxylic dianhydride
PTCDI-C ₁₃ H ₂₇	N,N'-ditridecylperylene-3,4,9,10-tetracarboxylic diimide
SEM	Scanning electron microscopy
SEP	Standard electrode potential
SF	Superfluorescence
SHG	Second harmonic generation
SiO ₂	Silicon dioxide

SMU	Source-measure unit
spiro-SBCz	2,7-bis[4-(N-carbazole)phenylvinyl]-9,9'-spirobifluorene
Ta ₂ O ₅	Tantalum pentoxide
TCO	Transparent conductive oxides
TE	Transverse electric
THF	Tetrahydrofuran
Ti	Titanium
TiO ₂	Titanium dioxide
TMAH	Tetramethylammonium hydroxide
TSL	Thermally stimulated luminescence
UV	Ultra violet
VR	Vibronic relaxation
Yb	Ytterbium
Zn	Zinc