ELECTRO-OPTICAL STUDIES OF ORGANIC LIGHT EMITTING DEVICES FOR EFFICIENCY ENHANCEMENT

By

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INSTRUMENT DESIGN DEVELOPMENT CENTRE

submitted in fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE 2012

CERTIFICATE

This is to certify that the thesis entitled **"ELECTRO-OPTICAL STUDIES OF ORGANIC LIGHT EMITTING DEVICES FOR EFFICIENCY ENHANCEMENT"** being submitted by **Arunandan Kumar** to the Indian Institute of Technology Delhi for the award of the degree of "**DOCTOR OF PHILOSOPHY**", is a record of the authentic research work carried out by him under our supervision and guidance. He has fulfilled all the requirements for submission of this thesis, which to the best of our knowledge has reached the required standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any other degree.

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ACKNOWLEDGEMENT

My thanks are firstly due to my supervisors Dr. D. S. Mehta and Dr. M. N. Kamalasanan. This thesis is the product of many hours of profound and fruitful discussion with them. They have helped me throughout my Ph.D. work. I would like to thank Dr. Ritu Srivastava for her continuous help throughout my work. I have learnt most of the experimental techniques from her. I would like to thank my SRC/CRC members Prof. A. L. Vyas, Dr. I. P. Singh, Dr. N. K. Jain and Prof. Joby Joseph for always pointing out mistakes in my work and for their suggestions to improve them

I will always been indebted to students working in the group. I am highly thankful to Dr. Gayatri Chauhan for spending her valuable time to help me in my initial learning process. My sincere thanks are due to Dr. Virendra Kumar Rai and Mr. Hemant Kumar for teaching me the experimental technique. I must thank Miss Priyanka Tyagi and Mr. Amit Kumar, with whom I spent many hours recovering from the inconclusive meetings and frustrations of experimental work. Especially, I am thankful to Priyanka for stimulating discussions and for her innovative suggestions in my thesis work throughout this period. To Mr. Amit Kumar and Amit Kumar Singh Chauhan, I am especially thankful for having mood freshening discussions during tea. At the same time, the contribution of other lab students Miss Manisha Bajpayee, Mr. Razi Ahmed, Miss Omwati and Miss Rakhi Grover at NPL and Mr. Gyanendra at IIT Delhi could not be forgotten. I would not be able to perform my work without the help and kind support of Mr. Hemant in arranging the necessary materials for experiments.

I would like to thank my friends Mr. Shailendra Jain, Mr. Brijesh Kumar, Mr. Suresh Chandra Kandpal, Mr. Ram Niranjan, Mr. Vivek Kumar, Mr. Anurag Jain, Mr. Pankaj Kumar for always being in touch during my Ph.D. work. I thank CSIR for providing the financial assistance to aid the Ph.D. work.

At last, I express deep sense of gratitude to my parents and family members whose support and inspiration in various stages of my research work have greatly helped me to realize this work.

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ABSTRACT

Organic light emitting devices (OLEDs) are developed in the 20^{th} century and grabbed much attention due to their wide applicability in modern displays and solid state lighting. OLEDs are fabricated using organic semiconductors (OSCs). OSCs are broadly categorized into two types, (a) small molecules and (b) long chain polymeric molecules. OSCs are composed of carbon, hydrogen and other low atomic number atoms like oxygen, sulphur, nitrogen etc. The electronic and optical properties of OSCs are due to carbon atoms, which can be explained by using the concept of hybridization. Carbon can possess three types of hybridizations: sp, sp^2 and sp^3. The OSCs in which carbon possesses sp^2 hybridization are used in OLEDs. Due to sp^2 hybridization, these carbon atoms have three σ bonds (corresponding to sp^2 orbital) and one π bond (corresponding to p_z orbital). The σ bond holds the molecule together, while the π electrons in π bonds are delocalized over the molecule. Due to these π electrons, OSCs, used in OLEDs, have good electrical and optical properties. Enormous amount of work has been performed on OLEDs based on these sp^2 hybridized OSCs. Still, the efficiency of OLEDs is needed to be improved. Efficiency of OLED depends upon charge carrier balance inside emissive layer, radiative emission efficiency of excitons formed inside emissive layer and efficient light outcoupling.

In this thesis, we have focused on the optimization of charge carrier balance, radiative recombination efficiency and optical outcoupling efficiency. Chapter 1 provides an introduction, different types, and various applications of OLEDs. In chapter 2, details of experimental techniques used in the fabrication of sample devices, instruments involved in the characterization of these devices have been described. The methods used for the determination of thin film properties of OLEDs are also discussed later in the chapter.

Chapter 3 presents the results of the studies on electrical properties of OLEDs. This work is focused on electron transport materials tris (8-hydroxyquinoline) aluminum (Alq_3), 5,5'-(2,6-di-tert-butylanthracene-9,10-diyl)bis(2-p-tolyl-1,3,4-oxadiazole) (OXD-PTOL). The electron only devices are fabricated using Alq_3 and OXD-PTOL. The results of OLEDs using these two materials are also presented in this chapter and their comparison as an electron transport material is discussed. Also the effect of mixing highly ordered organic semiconductor (8-hydroxy quinolinato) lithium (Liq) in these two organic materials on their electron transporting properties has been studied. Optimization of the concentration of Liq for better efficiencies of OLEDs is also performed in this work.

In chapter 4, we have described the interaction of the surface plasmons (SPs) formed at noble metal (gold, silver) nano-clusters with excitons and their effect on the fluorescence efficiency of organic materials. In this work gold and silver nano-clusters (GNCs and SNCs) were deposited using vacuum evaporation technique. The SP wavelength of 545 nm and 445 nm were measured for Au and Ag nano-clusters (NCs), respectively. Therefore, Au NCs were used with green emissive material $Ir(ppy)_3$ and Ag NCs with blue emissive material BCzVBi. The interaction between the SPs and excitons were studied using steady state and transient PL spectroscopy by varying the size of NCs. Excited state life time has been calculated from the transient PL spectra and found to be decreased from 0.35 μsec to 0.1 μsec and from 4.5 nsec to 2.2 nsec for $Ir(ppy)_3$ and BCzVBi, respectively. PL intensity has increased by about 3.2 times for $Ir(ppy)_3$ and 1.8 times for BCzVBi.

Chapter 5 provides the results of the OLEDs fabricated using Au and Ag nano-clusters incorporated inside the structure and the optimization of their location in the structure. The nano-clusters were incorporated inside the device at different locations. The cluster density has been optimized in order to get same current density as for the device without NCs. GNCs were used for green OLED and SNCs for blue. The enhancement of about 2.8 times and 1.8 times in the luminous efficiency was found for the green and blue OLED respectively for a distance of 5 nm between the emissive layer and NCs.

Chapter 6 deals with the extraction efficiency improvement of the OLEDs using glancing angle deposited (GLAD) nano-porous films of ITO. In this work, we have deposited nanostructured films of ITO by rf sputtering technique at glancing angles of 65^0, 75^0 and 85^0.The optical parameters such as optical transmission and refractive index are measured for these films. The films were found to have refractive indices of n=1.8 - 1.9, 1.4 - 1.5 and 1.2 - 1.25 for the glancing angles 65^0, 75^0 and 85^0, respectively compared to the refractive index of 1.8-1.9 for continuous ITO films grown for normal incidence. The films fabricated at glancing angle 85^0 were found to be optimum and were incorporated in the device at ITO/ glass and glass/ air interface. These films cause the enhancement of extraction efficiency by about 2.5 times.

Chapter 7 provides the study of nano-phosphor coated OLEDs for white light generation (down conversion) as well as for extraction efficiency enhancement. We have fabricated down converted white organic light emitting diodes (WOLEDs) by using cerium doped YAG nano-phosphor after mixing them in binder poly venyle acetate (PVAc) polymer matrix by changing the concentration of nano-phosphor. Down conversion layer was deposited by using a low cost spin coating technique. The enhancement in extraction efficiency by a factor of about 1.6 was found comparable to other expansive techniques for the fabrication of down conversion layer.

In chapter 8, we have listed the conclusions from the research work carried out in this thesis and also we have discussed the future scope of work in this chapter.

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