

Numerical Simulation of Bilayer Polymer Light-Emitting Diodes

Sanjay Tiwari* and N.C.Greenham

Cavendish Lab., University of Cambridge, J.J. Thomson Avenue, Cambridge CB3 0HE UK

Email: drsanjaytiwari@gmail.com

Abstract

A numerical model for the electrical properties for polymeric light emitting diodes (PLEDs) is presented which accounts for drift-and diffusion transport, recombination and re-emission processes.

I. Introduction

Since the report of electroluminescence from organic conjugated polymers back in 1990 by Burroughes *et al.*, [1] there has been significant progress in improving the characteristics and prolonging the lifetime of polymer light emitting diodes (PLEDs). Such PLEDs have a number of important potential advantages that include the possibility of fabrication on flexible substrates as well as at very low cost.

PLEDs consist of a thin typically about 100 nm layer of a conjugated luminescent polymeric material sandwiched between metallic contacts. The poor performance of Single layer PLED can also be improved by using a bilayer device, where the new material acts as a blocking layer. By blocking the carrier that is injected efficiently, the device quantum efficiency improves but the applied voltage needed to drive a given device current increases.

The simulation results on multilayer polymer devices allow for a deeper understanding of charge accumulation, electric field and recombination zone confinement effects due to internal interfaces. In this paper we will discuss.

simulation methodology and the specific simulation models used

II. Simulation Methodology

The electrical behaviour of organic light emitting diodes can be predicted by solving a self-consistent numerical model. Numerical method solving ID model based on drift-diffusion, continuity and Poisson's

equations extended by boundary conditions in treatment of internal organic interface is applied. The obtained space charge densities were employed in the emissive singlet exciton continuity equation resulting in the singlet exciton distribution and the emission zone profile. In the bulk, bipolar charge transport with field-dependent mobilities and Langevin bimolecular recombination is described by the following system of equations [2]

$$\frac{dh}{dt} = \frac{d}{dz} \left[\mu_n n E + \mu_n \frac{k_B T}{e} \frac{dh}{dz} \right] - \frac{n p e}{\epsilon_0 \epsilon_r} (\mu_n + \mu_p) = 0 \quad (1)$$

$$\frac{dp}{dt} = \frac{d}{dz} \left[\mu_p p E - \mu_p \frac{k_B T}{e} \frac{dp}{dz} \right] - \frac{n p e}{\epsilon_0 \epsilon_r} (\mu_n + \mu_p) = 0 \quad (2)$$

$$\frac{dE}{dz} = \frac{e}{\epsilon_0 \epsilon_r} (p - n) \quad (3)$$

Here, n is the density of electrons, p the density of holes, and E the electric field. Equation (1) describes the net current J_e of electrons composed of the drift and diffusion term, which are to satisfy the Poisson equation, Eq. (3).

Mobilities are taken to be field dependent with the Poole–Frenkel-like form

$$\mu(E) = \mu_0 \exp\left(\sqrt{E/E_0}\right) \quad (4)$$

added. The Langevin rate can be expressed as follows :

$$r = q (\mu_n + \mu_p) / \epsilon \epsilon_0 \quad (5)$$

In addition to the Langevin recombination rate model, the ability to calculate the singlet exciton density (S) was added. The exciton rate equation [3] is self-consistently solved with the Poisson equation and the electron and hole continuity equations. In one dimension the exciton rate equation can be expressed as

$$\frac{dS(x,t)}{dt} = \gamma(x,t)n(x,t)p(x,t) + D_s \frac{d^2S(x,t)}{dx^2} - \frac{S(x,t)}{\tau} \quad (6)$$

where $\gamma = 1/4$, following the simple spin statistics argument. The exciton diffusion constant is defined as $D_s = l^2/\tau$, with l being the diffusion length and τ the exciton lifetime.

Solving the two-dimensional form of Eq. 6 allows the examination of the spatial evolution of luminescence. The exciton diffusion length l can be considered to be the emission zone width. The boundary conditions for injection of charges at the electrodes require special attention for the case of PLEDs.

III. RESULTS & DISCUSSION

The simulation results were compared to the experimental results. These results compare favorably with transient data for PF₃ based bilayer LEDs, confirming that the electric field is predominantly dropped across the PF and that the delay time is determined by the electron transit time therein. Simulations also confirm that only high concentrations of traps affect the space-charge-limited currents in organic LEDs.

The numerical solution of two-dimensional form of Eq. 6 allows the

where μ_0 is the zero field mobility and E_0 the characteristic field.

The bimolecular Langevin recombination rate model for electrons and holes has been examined (the spatial evolution of luminescence). The exciton diffusion length l can be considered to be the emission zone width. Exciton quenching near electrodes was found to occur (Fig.1). The presence of metal electrodes is believed to increase the radiative lifetime significantly and therefore lower the luminous efficiency by allowing non-radiative decay channels to play a dominant role. For PPV-type polymers the quenching zone extends as far as 20 nm from the electrode [3].

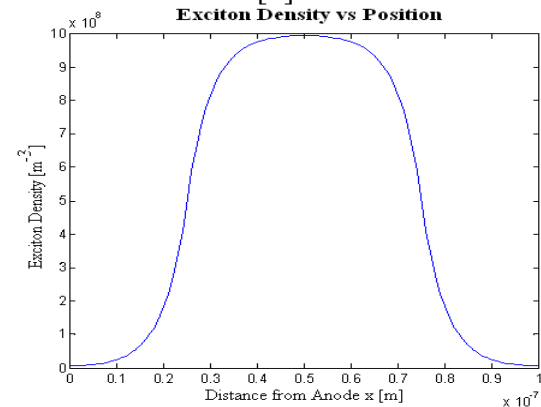


Fig.1 Exciton decay with position from anode

REFERENCES

1. J. H. Burroughes ,D.D.C. Bradley , A.R. Brown,R.N. Marks ,K. Mackay ,R.H. Friend, P.L.Burn, and A.B.Holmes, "Light-Emitting Diodes Based on Conjugated Polymers "Nature **347**, 539,1990
2. G.G.Malliaras, „J.C. Scott,“ The roles of injection and mobility in organic light emitting diodes” J. Appl. Phys. 83, 5399,1998
3. B. Ruhstaller, S.A. Carter, S.Barth, H. Riel, W .Riess, W., J.C. Scott, : "Transient and steady-state behavior of space charges in multilayer organic light-emitting diodes,"J.Appl.Physics,89,4575,2001