Bipolar Transport Model of Single Layer OLED for Embedded System

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Abstract We present a device model for organic light emitting diodes(OLEDs) which includes charge injection, transport, recombination, and space charge effects in the organic materials. The model can describe both injection limited and space charge limited current flow and the transition between them. Calculated device current, light output, and quantum and power efficiency are presented for different cases of material and device parameters and demonstrate the improvements in device performance in bilayer devices. These results are interpreted using the calculated spatial variation of the electric field, charge density and recombination rate density in the device. We find that efficient OLEDs are possible for a proper choice of organic materials and contact parameters.

Keywords : OLED(Organic Light Emitting Diode), Display, Organic semiconductor, Information device.

1. Introduction

Semiconductors have been at the origin of the most important industrial revolution of the 20th century, which has been dominated by the development of electronics. Development of semiconductor came with having many changes of life. Among them, the most notable change is change of display devices. Now, display devices are change by organic material semiconductor in inorganic material semiconductor.

Over the last 10 years, Organic Light Emitting Diodes(OLEDs) have been a subject of intensive research. This is a new type of electronic device that offers many advantages over the existing display technologies. The first displays based on organic semiconductors have become commercially available and companies like Pionner and Philips and many other are currently developing this promising technology. The large interest in not only caused by technological aspects such as the low costs, the possibility to prepare flexible large area devices at low process temperature on polymer foils, and the almost unlimited variety of organic compounds that allow tuning of e.g. energy levels and emission colors.

Information storage device can refer to data that say that is information as general term of that remake recording. We must make device so that OLED can information storage must do behaves of switching to do role as information device as well as display devices. This paper studied OLED about OLED's switching function to be utilized by information device.

2. Schematic of an OLED

A schematic cross section of a conventional, small molecule based OLED with three organic layers are shown in Figure 1. The top, ohmic, electron-injecting electrode consists of a low work function metal alloy, typically Mg-Ag or Mg-Au, deposited by vacuum evaporation. The bottom, hole-injecting electrode is typically a thin film of the transparent semiconductor

ITO(Indium Tin Oxide), deposited onto the substrate by sputtering or electron beam evaporation.

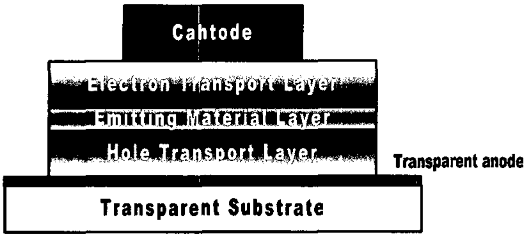

Figure 1. Schematic cross section of an OLED.

2.1 Single Layer OLED

The operation principle of a single layer OLED is schematically shown in Figure 2. For such devices, the exciton recombination region is near the middle of the device if injection of holes from the anode and electrons from the cathode into the organic material is equally effcient, and the mobilities for both carrier types are also equal.

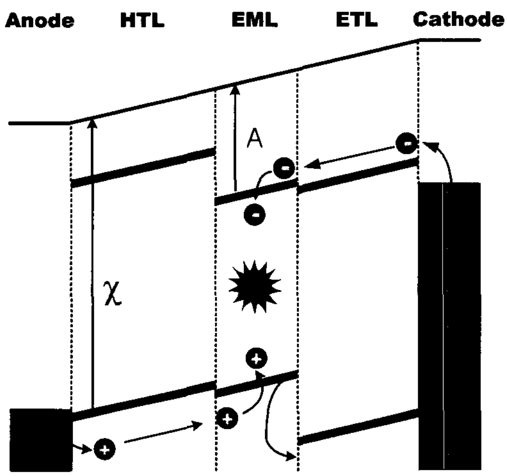

Figure 2. Energy level scheme for a single layer of OLED.

An electron transport layer(ETL) is inserted between the EML and the cathode. It should have a wider HOMO(Highest Occupied Molecular Orbital)-LOMO(Lowest Unoccupied Molecular Orbital) gap and a larger ionization potential than the EML so that neither excitons nor holes from the EML can pentrate into the ETL. Therefore, this layer is variously refered to as the hole-blocking or exciton blocking layer.

2.2 Bipolar Transport Model of OLED

The transport of electrons and holes in organic device can be solved by the continuity equation, with a drift-diffusion equation, coupled to Poisson's equation. Energy level discontinuities at the organic hetero-junction can be used to produce an energy barrier that blocks charge transport across the structure.

$$\frac{dJ_n}{dx} = -q(G-R) \qquad (1)$$

$$\frac{dJ_p}{dx} = q(G-R) \qquad (2)$$

$$\frac{d^2\psi}{dx^2} = -\frac{q}{\varepsilon}(p-n) \qquad (3)$$

where J_n and J_p are the electron and hole current densities, respectively. Electrostatic potential ψ are function of the length of the device, q is the electric charge and ε is the static dielectric constant. The optical recombination rate R is given by $R = \gamma\ n\ p$, where $\gamma = 4\pi q \mu_R / \varepsilon$ is Langevin recombination coefficient. The generation of electron hole pair (EHP) is given by $G = \gamma\ n_e p_e$, where n_e, p_e is thermal equilibrium electron and hole carrier density. Effective recombination mobility μ_R taken to be larger either the hole mobility μ_p or the electron mobility μ_n.

In equilibrium, the electron density n and the hole density p is represented to n_e and p_e using Maxwell-Boltzmann statistics,

$$n_e = n_0 \ \exp\left(\frac{q\psi - q\phi_F + \chi_C}{kT}\right) \qquad (4)$$

$$p_e = p_0 \ \exp\left(-\frac{q\psi - q\phi_F + \chi_C + E_g}{kT}\right) \qquad (5)$$

where ϕ_F is the Fermi level in equilibrium and χ_C is the electron affinity. T is the temperature in Kelvin and k is the Boltzmann's constant. n_0 is molecule's density of state and E_g is energy gap.

The drift-diffusion equations defining the electron and hole currents, J_n and J_p are

$$J_n = q\,\mu_n\left(n\,E + \frac{kT}{q}\frac{dn}{dx}\right) \quad (6)$$

$$J_p = q\,\mu_p\left(p\,E - \frac{kT}{q}\frac{dp}{dx}\right) \quad (7)$$

where the electric field is given by $E = -d\psi / dx$, the electron and hole mobility is given by $\mu_n = \mu_{n0}\exp(E/E_0)$ and $\mu_p = \mu_{p0}\exp(E/E_0)$, respectively. μ_{p0} and μ_{n0} is hole and electron mobility in zero electric field, respectively. The equations are solved numerically using a Sharfetter-Gummel spatial discretization method,

$$J_{p_{i+\frac{1}{2}}} = \frac{kT\mu_p}{\Delta x}\left[p_i B\left(\frac{q\psi_{i+1} - q\psi_i}{kT}\right) - p_{i+1}B\left(\frac{q\psi_i - q\psi_{i+1}}{kT}\right)\right] \quad (8)$$

$$J_{n_{i+\frac{1}{2}}} = \frac{kT\mu_n}{\Delta x}\left[n_{i+1}B\left(\frac{q\psi_{i+1} - q\psi_i}{kT}\right) - n_i B\left(\frac{q\psi_i - q\psi_{i+1}}{kT}\right)\right] \quad (9)$$

where $\Delta x = x_{i+1} - x_i$ is differential mesh size, $B(y) = y/(\exp(y) - 1)$ is function of Bernoulli.

At the metal-organic-metal contact, there are boundary conditions. Firstly, total current is sum of thermionic current from $x = 0$ to $x = L$ and back-flowing interface recombination current and FN (Fowler-Nordeim tunneling) current,

$$J_p(0) = -qv_{rp}\left(p_e[E(0)] - p(0)\right) - \left(J_{tp}|_{x=0} - J_{tp0}|_{x=0}\right) \quad (10)$$

$$J_n(L) = qv_{rn}\left(n_e[E(L)] - n(L)\right) + \left(J_{tn}|_{x=L} - J_{tn0}|_{x=L}\right) \quad (11)$$

where electron and hole's effective recombination velocity are respectively.

$$v_{rn} = 16\pi\varepsilon\mu_n (kT)^2 / q^3 \quad (12)$$

$$v_{rp} = 16\pi\varepsilon\mu_p (kT)^2 / q^3 \quad (13)$$

And the hole and electron density of quasi-equilibrium at $x = 0$, $x = L$ is

$$p_e[E(0)] = n_0 \exp\left(-\frac{\varphi_{bp} - \Delta\varphi_{bp}}{kT}\right) \quad (14)$$

$$n_e[E(L)] = n_0 \exp\left(-\frac{\varphi_{bn} - \Delta\varphi_{bn}}{kT}\right) \quad (15)$$

where Schottky hole and electron electric potential barrier are φ_{bp}, φ_{bn}. If φ_{bp} and φ_{bn} are negative electric potential, there are barrier lowering by image force. In this case the model also incorporates image force lowering of the barrier at contacts.

$$\Delta\varphi_{bp} = \sqrt{qE(0)/4\pi\varepsilon} \quad (16)$$

$$\Delta\varphi_{bn} = \sqrt{qE(L)/4\pi\varepsilon} \quad (17)$$

The Fowler-Nordheim currents take the form

$$J_{tp}|_{x=0} = C_p E(0)^2 \exp\left(-\frac{\kappa_p}{E(0)}\right) \quad (18)$$

$$J_{tn}|_{x=L} = C_n E(L)^2 \exp\left(-\frac{\kappa_n}{E(L)}\right) \quad (19)$$

where constant coefficient is given by

$$C_p = 3q^2 / 8\pi h\left(\varphi_{bp} - \Delta\varphi_{bp}\right) \quad (20)$$

$$\kappa_p = 8\pi\sqrt{2qm}\left(\varphi_{bp} - \Delta\varphi_{bp}\right)^{3/2} / 3h \quad (21)$$

$$C_n = 3q^2 / 8\pi h\left(\varphi_{bn} - \Delta\varphi_{bn}\right) \quad (22)$$

$$\kappa_n = 8\pi\sqrt{2qm}\left(\varphi_{bn} - \Delta\varphi_{bn}\right)^{3/2} / 3h \quad (23)$$

The position independent of the total current $J = J_p + J_n$ is used to verify that steady state has been reached. At steady state, one can obtain the recombination current $J_r = J_p(0) - J_p(L)$. These quantities are related to the quantum efficiency $\eta_q = QJ_r / J$, and power efficiency $\eta_p = Q(J_r / J)(E_g / V)$ by multiplying the ratio of radiative to total recombination. The ratio of radiative to total recombination is $Q = 1/4$ because of a quarter of the excitons forms are singlets.

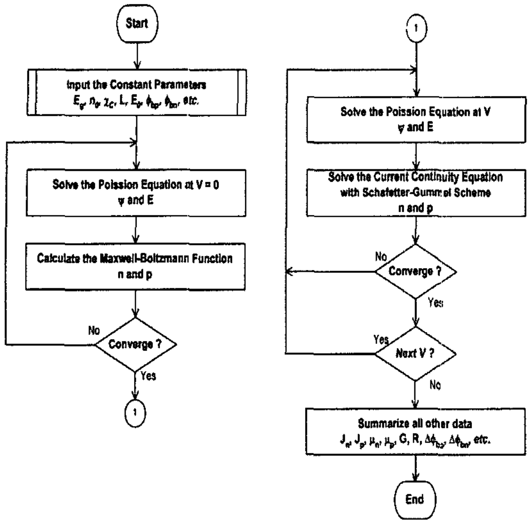

Figure 3. Flow chart Simulation of OLED.

Figure 3 is flow chart for simulation of bipolar transport layer in OLED.

3. Simulation results

The energy diagram in equilibrium scheme of ITO/MEH-PPV/Al structure is shown in Figure 4. We can know that energy level of equilibrium state influences in distance from Figure 4.

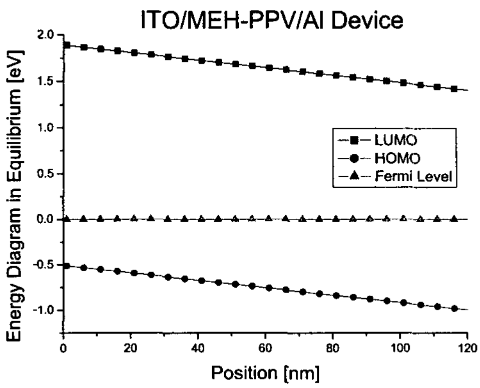

Figure 4. Energy diagram scheme in equilibrium.

The energy diagram scheme of applied bias state of ITO/MEH-PPV/Al structure is shown in Figure 5. By applied voltage, energy level is changed.

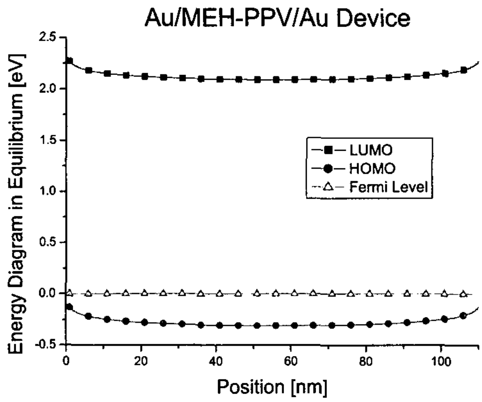

Figure 5. Energy diagram scheme in non-equilibrium.

The schottky barrier lowering phenomenon of ITO/MEH-PPV/Al structure is shown in Figure 6. Because OLED is thin film structure, if bias applied voltage that current is passed in tunneling phenomenon.

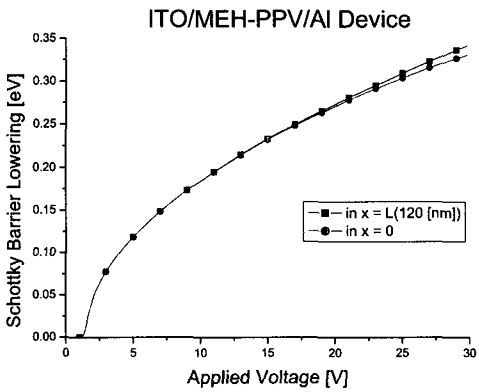

Figure 6. Schottky barrier lowering phenomenon.

4. Conclusions

This research progressed for electric charge transport mechanism for organic material electroluminescence that have ITO/MEH-PPV/Al structure. In case of ITO/MEH-PPV/Al structure, if Schottky barrier is more than 0.4 [eV] anode and interface of emitting light layer and cathode and interface of emitting light layer, transport characteristic of electric charge is been influenced at interface. That is, characteristic of electric charges that transport device is less, and the density is fixed and knew that is seldom change of electric field at each point of device interface.

These results are interpreted using the calculated spatial variation of the electric field, charge density and recombination rate density in the device. We find that efficient OLEDs are possible for a proper choice of organic materials and contact parameters.

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