Theoretical Approach to the Effect of Traps on the Performance of Organic Light Emitting Diode

[1]Nisha Bhatt, [2]P. K. Khare
[1] Professor, Deptt of Electronics and Communication, LNCT, Jabalpur, India
[2]Professor, Deptt of Post graduate studies in Physics and Electronics, Rani Durgavati Vishwa Vidyalaya, Jabalpur, India

Abstract: **Charge traps in organic light emitting diode are introduced by the defects and these traps act as a charged centre, which capture free charge carrier (electron or hole), which can be released later, when a favorable energetic condition occurs. A trap that captures an electron is an electron trap (acceptor type). Both traps are initially neutral and become charged when filled, negatively for an electron trap and positively for a hole trap. Depending on its energetic level with respect to HOMO or LUMO edges, a trap can be shallow or deep. Present paper discusses the effect of traps on the performance of organic light emitting diodes.**

Key words**: Electroluminescence, electron traps. hole traps, hopping transport**

I. INTRODUCTION

Electroluminescence (EL) is the result of electric field-imposed formation of emissive states without recourse of any intermediate energy forms, such as heat. In its most basic form, an organic light emitting diode consists of a series of vacuum deposited small –molecule organic thin films that are sandwiched between two thin film conductors[1]. The effective rate of carrier injection across the interface is very much lower than the rate of injecting hops, since most of them are followed by back injection into the initial layer. The hopping transport that happens across the heterojunction of two organic layers majorly depends on the net carrier flow imposed by the external electric field. The effect of energetic disorder in the two layers is addressed separately. Traps affect not only the current and recombination, but also the transient time required for the device to reach the steady state. A time scale of millisecond arises in bipolar devices with higher trap density. In PLED, traps cause the recombination zone to approach the cathode, seriously affecting the device luminescence and efficiency due to the metal quenching. Addition of hole traps recovers the balance of carrier densities and doubles the efficiency.

II. THEORY

The emission wavelengths in OLED can be modified by blending dopants into the polymers light emitting diodes or by the incorporation of fluorescent dyes into the emissive layers for small molecular devices. In organic light emitting diodes, carriers are localized in molecules and charge transport is a hopping process. Carrier mobility is determined by charge transport between neighboring hopping sites. The mobility usually shows the Poole- Frenkel characteristics. By controlling the distance between the hopping sites, carrier mobility can be adjusted. At thermodynamic equilibrium, charge carriers mostly occupy the deep tail states of the density of states distribution. Carrier hopping occurs mostly via shallower states. This shows that carrier density could affect mobility. Furthermore, dopants in organic light emitting diodes act as shallow trapping centers, which trap carriers and change the carrier density.

Carrier trapping is the main emission mechanism in doped organic systems. This also shows the dependence of the mobility on the dopant concentration. Although the efficiency of doped OLEDs has been improved but to further improve the efficiency and lifetime of the OLEDs carrier transport and recombination dynamics of organic light emitting diodes should be explored. In the study of the dependence of carrier transport behavior and luminescence mechanism on dopant concentration of OLEDs, it is found that, in lightly doped sample, higher carrier mobility and better device performance were observed. This shows that dopants create additional hopping sites and shorten the hopping distance. At a higher doping concentration, dopants tend to aggregate and the aggregations degrade the device performance.

Generally, disorder, structural disorder and impurities in the organic semiconductor create traps, which control the transport properties of the organic semiconductors. These traps reduce the number of mobile carriers and detain the charges for a long time and so the traps become charge storage sites[2,3] .These traps introduce energy levels inside the energy gap between the HOMO and the LUMO of the organic layers. Charging and discharging of these trap levels can play an important role in the operation and performance of the organic light emitting diodes (OLEDs).

One of the most unique properties of a conjugated polymer is that the hole mobility is much higher than the electron mobility. This mobility imbalance is expected to be the main limit for the quantum efficiency of the device. There are two reasons causing the higher hole mobility, both related to the electron traps. The first is that the background p-doping compensates for the hole traps caused by the structural defects, the second is that Oxidation contributes to electron traps, but not to hole traps. In addition to reducing the electron mobility, the electron traps may confine the electroluminescence (EL) near the cathode. The imbalanced carrier mobility manifests not only in the absolute value, but also in its dependence on the electric field. The field dependence of electron mobility exceeds that of hole mobility and this phenomenon can also be explained by the existence of electron traps. Exponential energy distribution of traps is assumed for modeling the device. The trap density of states has the form.

$$n_{te(\varepsilon,x)} = \frac{N_t(x)}{kT_t} \exp \frac{(E-E_c)}{kT_t} \quad \text{... (1)}$$

where $N_t\ (x)$ is the trap density in position x, KT_t is the characteristic energy of traps, which is the depth of traps from the conduction band edge E_c. The free electrons are assumed to be in thermal equilibrium with trapped electrons. Using the above equation and approximating the Fermi- Dirac distribution as a step function, a relationship between the trapped carrier N_t and free electrons density can be obtained and is given by

$$N_t = \boldsymbol{N_i} \left(\frac{\boldsymbol{n_f}}{\boldsymbol{n_o}}\right)^{\boldsymbol{T}/\boldsymbol{T_t}} \quad \text{... (2)}$$

where n_o is the effective density of states for free electrons.

In a single layer device model[4], which comprises of a thin film layer of organic semiconductor sandwiched between two electrodes, the transport of electrons and holes are described by time-dependent continuity equations with drift-diffusion current, coupled with Poisson's equation.

$$\frac{dn_{to}}{dt} = \frac{1}{e}\left(\frac{\partial J_n}{\partial x}\right) + G - R \quad \text{---------- (3)}$$

$$\frac{dp}{dt} = -\frac{1}{e}\left(\frac{\partial J_p}{\partial x}\right) + G - R \quad \text{---------- (4)}$$

$$\frac{\partial E}{\partial X} = \frac{e(p-n_f-n_t)}{\varepsilon} \quad \text{---------- (5)}$$

where $n_{to} = n_f + n_t$

and J_n and J_p are given by equations

$$J_n = e\mu \left[n_f E + \frac{kT}{e}\frac{\partial n_f}{\partial x}\right] \quad \text{---------- (6)}$$

$$J_p = e\mu\left[pE - \frac{kT}{e}\frac{\partial p}{\partial x}\right] \quad \text{---------- (7)}$$

where n_{to} is the total election density, including free (n_f) and trapped (n_t) electrons, p is the hole density, J_n (J_p) is the electron (hole) current density and G and R are the generation and recombination rate, respectively, x is the position normal to the film and the cathode is at x = O, t is the time, e is absolute electron charge, and μ is the free – carrier mobility. μ is same for electrons and holes. E is the electric filed, K is Boltzmann's constant, T is the temperature, and $E = E_0 E_r$ is the permittivity of the material.

The recombination rate R is bimolecular, which takes the form.

$$R = r\, n_f\, p \quad \text{---------- (8)}$$

where r is Langevin recombination coefficient given by

$$r = \frac{e\mu}{\varepsilon} \quad \text{---------- (9)}$$

substituting the value of n_t i.e.

$$n_t = N_i \left(\frac{n_f}{n_o}\right)^{T/T_t} \quad \text{---------- (10)}$$

in equation (3)

$$\frac{\partial n_f}{\partial t} = \frac{1}{1+B}\left(\frac{1}{e}\frac{\partial J_n}{\partial x} - r n_f p\right) \quad \text{---------- (11)}$$

$$\frac{\partial n_t}{\partial t} = \frac{1}{1+B}\left(\frac{1}{e}\frac{\partial J_n}{\partial x} - r n_f p\right) \quad \text{---------- (12)}$$

where

$$B = N_t \frac{T}{T_i}\left(\frac{1}{n_o}\right)^{T/T_t} \frac{1}{n_f^{1-T/T_t}} \quad \text{---------- (13)}$$

These equations are integrated together with the equation for the electric field

$$\frac{\partial E(x,t)}{\partial t} = -\frac{1}{L}\frac{\partial V_L}{\partial t} - \frac{1}{\varepsilon}\left[J_t(x) - \frac{1}{L}\int_0^L J_t(x)dx\right] \quad \text{---------- (14)}$$

where V_L is the voltage at the anode, V = O ,at cathode, and L is the thickness of the device.

The efficiency η is shown in Fig. 1 as a function of the trap density N_t and the applied voltage. When N_t increases, the efficiency declines faster at a smaller voltage than that at a higher voltage, suggesting that the imbalance between the electron and hole current in the device with a smaller voltage exceeds that in the device at a higher voltage. Fig 2 shows the graph of current density versus trap concentration.

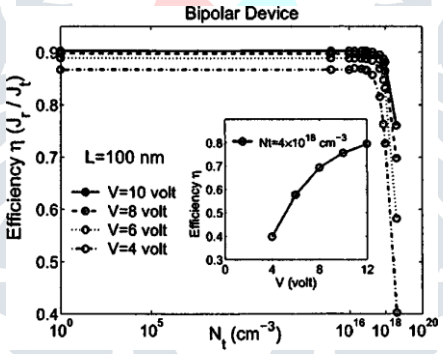

Figure 1. Efficiency versus trap density

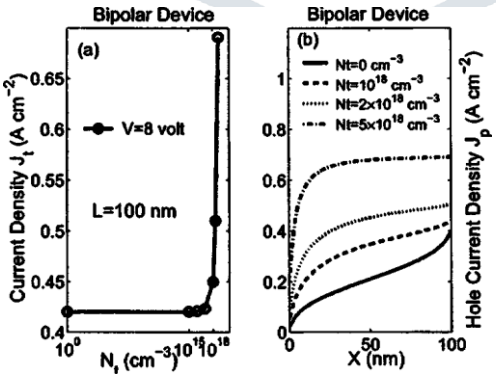

Figure 2. Current density versus trap concentration

III. CONCLUSIONS

In disordered organic materials[5] , carrier hopping is the dominant mechanism of charge injection and transport. At higher applied voltages the injection is more balanced and the cathode quenching is greatly reduced which increases the efficiency of the device. If the device structure has one ohmic contact and one injection limited contact, in this case, the carrier density balance and the mobility balance, both get change after the addition of traps. Therefore current balance is the central principle in determining the effect of traps on efficiency of organic light emitting diodes (OLEDs). The change in mobility balance due to traps is the dominant effect on efficiency. If charge traps for one type of carrier are introduced into an otherwise relatively trap-free organic material, changes in the relative injected carrier densities and relative carrier mobilities cause competing effects on the current density balance and, consequently, on the device efficiency. Charge carrier transport through organic semiconductors is strongly affected by trap states in the energy gap. Such states can be deliberately introduced by neutral doping with organic molecules which have an energy level within the energy gap of the host material. Such trap-induced decrease of the charge carrier mobility has been utilized to balance charge transport in organic light emitting diodes (OLEDs), resulting in an improved lifetime. The trapping effect can improve efficiency by increasing the recombination rate. If an impurity is introduced which acts as a trap for both carriers, will also increase the efficiency as long as the hole trap depth is larger than that for electrons. If both injection barriers are high, traps will help to improve efficiency by increasing the bimolecular recombination rate as a function of current density.

REFERENCES

[1] I. Arkhipov, H. Bassler, Y. H. Tak and E. V. Emelianova, J App. Phys.,84, 848 (1998)

[2] H. Bässler, Phys. Status Solidi B **175**, 15 s1993d.

[3] Y. N. Gartstein and E. M. Conwell, Chem. Phys. Lett. **245**, 351 (1995).

[4] M. J. Tsai and H. F. Meng, J App. Phys.,**97**, 114502 (2005)

[5] L. G. Kaake, P. F. Barbara and X. Y. Zhu, J Phys. chem, 1, 628 (2010)