

## Organic Light Emitting Devices for Display Applications and their Transient Behavior

**Manju Tiwari**

BRSM Collage of Agricultural Engineering and  
Technology & Research Station, Mungeli,  
Indira Gandhi Krishi Vishwavidyalaya,(C.G)India  
manjushukla2003@gmail.com

**Nameeta Brahme**

School of Physics & Astrophysics,  
Pt. Ravishankar Shukla University,  
Raipur(C.G)India  
namitabrahme@gmail.com

---

**Abstract:** Organic materials, by virtue of their light weight and greater ease of fabrication, have replaced and are continuing to replace metals in several areas of application; as often remarked “from buckets to rockets”. Over the past two decades there have been many exciting discoveries in organic materials that can be used as the active element in electronic and optoelectronic devices. The polymers which are semi-conducting and electroluminescent have led to even more exciting possibilities such as transistors and photo-detectors etc. In the present paper we have discuss a small portion of the huge world of Organic electronics and made an attempt towards developing a theory for the kinetics of transient behavior of Organic light emitting devices (OLED).

A model for transient electroluminescence OLEDs has been developed. A comparison of simulated results with experimental data available in the literature confirms validity of the developed model. According to the developed model a delay is expected in the EL onset and EL would rise and fall with rise and fall of the applied voltage pulse. The EL would first show a fast rise which would be followed by slow rise and finally saturation in EL would occur at sufficiently large time. At any time  $t$  the prompt increase in EL shows quadratic dependence on  $(t-t_D)$ , where  $t_D$  is the time delay observed in the onset of EL. While decaying the EL shows exponential dependence on  $(t-t_{off})$ , where  $t_{off}$  is the time when voltage is switched off.

**Keywords:** OLED, Transient EL, Organic semiconductors.

---

### 1. INTRODUCTION

Organic semiconductors have proved their potential for electronic devices such as light emitting diodes, solar cells, thin film transistors, lasers etc. [1-5]. After the first realization of EL in organic small molecular LEDs by Tang and VanSlyke in 1987 [6] and then by Burrounges *et al.* in polymer LEDs in 1990 [7], OLEDs have found applications in pulse light sources, high resolution displays and optical communications. For such type of optical application the understanding of physics behind transient EL in these devices is of prime importance. The OLEDs have shown EL emission spanning the visible and near infrared spectrum of light [8-15]. Efforts are being made to clarify the mechanism of charge injection and transportation in these devices. EL in OLEDs is governed by bimolecular recombination of injected charge carriers. However, when the number of trapped charge carrier is more than the number of free charge carries, there is also a possibility of monomolecular recombination. The EL in OLEDs involves many processes like charge carriers injection, transportation, formation of excitons and finally recombination to give light photons [3]. We developed a model for charge carrier kinetics in transient EL of OLEDs.

### 2. SIMULATION AND MODELING

A delay is expected in the onset of EL with respect to the voltage applied to the device due to delay in charge carrier injection and delay in charge carrier transportation before recombination. The injection delay depends on time constant and threshold voltage for charge injection whereas the charge transport delay time depends on the carrier mobility [16]. For bimolecular generation-recombination the rate of generation of excitons would be given by  $G = \gamma n^2$ , where  $\gamma$  is the bimolecular generation-recombination coefficient. A detailed calculation show that the expression of EL brightness in an OLED comes out to be [17]

$$\chi_{EL} = \frac{ALk_r N}{k_{ex}} \left[ \frac{\exp(\sqrt{N\gamma}(t-t_D)) - \exp(-\sqrt{N\gamma}(t-t_D))}{\exp(\sqrt{N\gamma}(t-t_D)) + \exp(-\sqrt{N\gamma}(t-t_D))} \right]^2 \quad (1)$$

where  $A$  is the active area,  $L$  is the thickness of the sample,  $k_r$  is the rate constants for radiative recombination,  $1/k_{ex}$  is exciton lifetime,  $t_D$  is delay in EL onset and  $N$  is the charge carrier density. For small values of  $\sqrt{N\gamma}(t-t_D)$  we get

$$\chi_{EL} = \frac{ALk_r N^2}{k_{ex}} \gamma (t-t_D)^2 \quad (2)$$

The small values of  $\sqrt{N\gamma}(t-t_D)$  will include small values of current density ( $J$ ) or voltage ( $V$ ). For very large values of  $(t-t_D)$  Eq. (1) gives

$$\chi_{EL} = \frac{ALk_r N}{k_{ex}} \quad (3)$$

Therefore for very large values of  $(t-t_D)$  the luminescence will attain saturation and will depend on  $J$  (or  $V$ ). The linear dependence of  $\chi_{EL}$  on  $J$  has also been observed by other authors [18, 19]. When the applied voltage is switched off the EL intensity does not decay to zero immediately but it decreases slowly. The density of excitons  $D_{ex}$  at any time  $t$  comes out to be [17]

$$D_{ex} = \frac{\gamma(N')^2}{k_{ex}[N'\gamma(t-t_{off}) + 1]^2} + \left( N'_{ex} - \frac{\gamma(N')^2}{k_{ex}} \right) \exp[-k_{ex}(t-t_{off})] \quad (4)$$

where  $N'$  is the saturated charge carrier density,  $N'_{ex}$  is  $N/k_{ex}$  and  $t_{off}$  is the time when applied voltage is switched off. For small values of  $(t-t_{off})$  Eq. (4) reduces to

$$D_{ex} = N'_{ex} \exp[-k_{ex}(t-t_{off})] \quad (5)$$

The light brightness while EL decay comes out to be

$$\chi_{EL} = ALk_r N'_{ex} \exp(-k_{ex}(t-t_{off})) \quad (6)$$

For the larger values of  $(t-t_{off})$  the value of EL brightness comes out to be

$$\chi_{EL} = ALk_r \frac{\gamma(N')^2}{k_{ex}[N'\gamma(t-t_{dec}) + 1]^2} \quad (7)$$

Let  $\chi_{EL,max}$  be the maximum value of  $\chi_{EL}$  and it is the case at  $t = t_{off}$ . Now  $\chi_{EL,max}$  will be given by

$$\chi_{EL,max} = ALk_r \frac{\gamma(N')^2}{k_{ex}} \quad (8)$$

We finally get

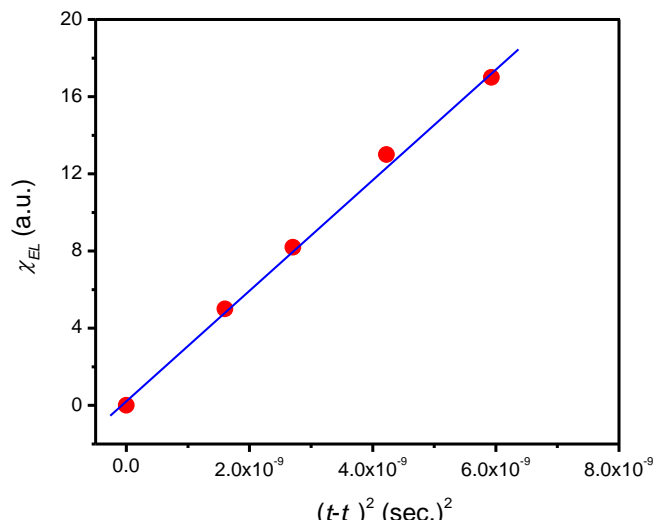
$$\left[ \frac{\chi_{EL,max}}{\chi_{EL}} \right]^{1/2} = [N'\gamma(t-t_{off}) + 1] \quad (9)$$

For high values of  $(t-t_{off})$ ,  $\left[ \frac{\chi_{EL,max}}{\chi_{EL}} \right]^{1/2}$  would vary linearly with  $(t-t_{off})$ .

### 3. COMPARISON OF SIMULATED RESULTS WITH EXPERIMENT DATA BY MARAI ET AL.

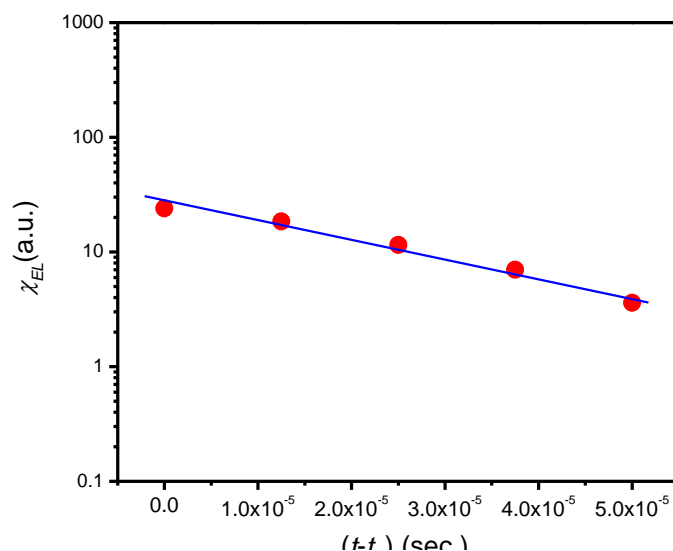
Marai *et al.* reported the transient studies on the current and EL in the OLED based on poly (ether-poly phyneylenerinylene) (PE-PPV) [20]. We compare our simulated results with the results of

Marai *et al.* at 4 V. The delay time was calculated to be  $10 \mu\text{s}$ . Fig 1 shows the comparison of our theory with the experimental data (symbols) extracted from the studies of Marai *et al.* [20]. Fig. 1 has been plotted for the variation of  $B_{EL}$  with  $(t-t_D)$  for small values of time  $t$ . It is seen that for the smaller values of  $(t-t_D)$ ,  $\chi_{EL}$  increases quadratically with  $(t-t_D)$ . This behavior is in accordance of Eq. (2) and supports its validity. It can be clearly seen from the studies of Marai *et al.* that for large values of time  $t$  the EL profile get saturated which supports the validation of Eq. (3).



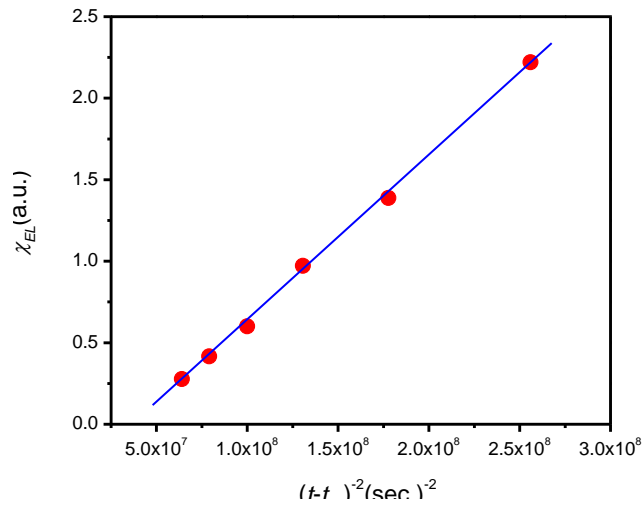
**Fig1.** Comparison of simulated and experimentally observed  $\chi_{EL}$  versus  $(t-t_D)^2$  for ITO/PE-PPV/Al, OLED prepared by Marai *et al.* [20]. Symbols represent the experimental data whereas straight line is the plot of simulated results.

When the voltage is turned off the EL starts decaying. Fig 2 shows the variation of EL intensity as a function of  $(t-t_{off})$  on the semi-log scale for smaller values of  $(t-t_{off})$ . Symbols represent the experimental data. It can be clearly seen that the plot is a straight line with a negative slope, which is in agreement with Eq. (6).



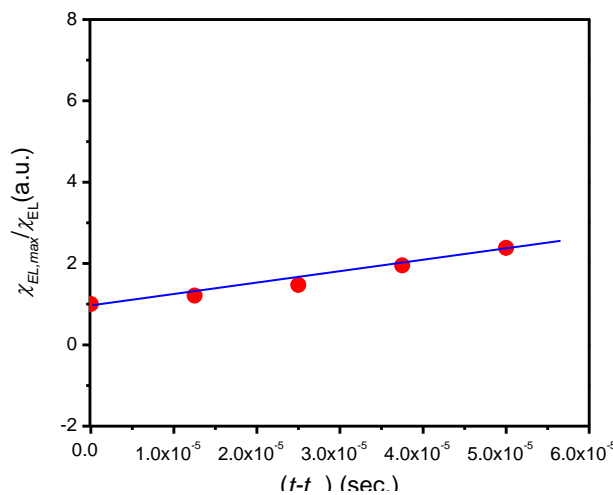
**Fig2.** Comparison of simulated and experimentally observed  $\chi_{EL}$  versus  $(t-t_D)$  for ITO/PE-PPV/Al, OLED prepared by Marai *et al.* for small values of  $(t-t_D)$ . Symbols represent the experimental data whereas straight line is the plot of simulated results.

Fig. 3 is also from the same data plotted between EL intensity and  $(t-t_{off})^{-2}$  for larger values of  $(t-t_{off})$ . It is seen that plot is a straight line with a positive slope. Such dependence of EL intensity on  $(t-t_{off})^{-2}$  is exactly the same as expected from Eq. (7).



**Fig3.** Comparison of simulated and experimentally observed  $\chi_{EL}$  versus  $(t-t_{off})^{-2}$  for ITO/PE-PPV/Al, OLED prepared by Marai et al. for larger values of  $(t-t_{off})$ . Symbols represent the experimental data whereas straight line is the plot of simulated results.

Fig. 4 shows that the plot between  $(\chi_{EL,max} / \chi_{EL})^{1/2}$  as a function of  $(t-t_{off})$ , is a straight line with a positive slope. This is the same result as expected from Eq. (9). It is to be noted that when the experimental results related to the initial rise and decay of  $\chi_{EL}$  for small and large values of  $(t-t_{off})$  are compared with the simulated results it is found that the experimental results follow the bimolecular recombination-based kinetics of the transient behavior of OLEDs. Thus the present investigation confirm that the light emission from present OLEDs takes place due to the radiative decay of singlet excitons produced during the bimolecular recombination of oppositely charged carriers injected from electrodes.



**Fig4.** Comparison of simulated and experimentally observed  $\left(\frac{\chi_{EL,max}}{\chi_{EL}}\right)^{1/2}$  versus  $(t-t_{off})$  for ITO/PE-PPV/Al, OLED, prepared by Marai et al. Symbols represent the experimental data whereas straight line is the plot of simulated results.

#### 4. CONCLUSIONS

In conclusion, the mathematical simulation on the charge carrier kinetics in transient EL of OLEDs has been presented. A time delay is observed in the onset of EL. Transient EL in OLEDs shows fast initial rise, which is followed by the rather slow rise and finally it attains the saturation. The fast rise of EL shows quadratic dependence on the  $(t-t_D)$ , while fast decay in EL shows exponential dependence on  $(t-t_{off})$ .

REFERENCES

- [1] Jain S.C., Willander M., Kumar V., *Conducting Organic Materials and Devices*, Academic Press: San Diego, (2007).
- [2] Kumar P., Chand S., Prog. Photovolt: Res. Appl. 20, 377 (2012).
- [3] A Misra., Kumar P., Kamalasanan M. N., Chandra S., Semi. Sci. Technol. 21, R35 (2006).
- [4] Logothetidis S., Mater. Sci. Enging. B 152, 96 (2008).
- [5] Logothetidis S., *Handbook of flexible organic electronics: Materials, manufacturing and applications*, Woodhead Publishing, Elsevier, (2015).
- [6] Tang C. W. and VanSlyke S., Appl. Phys. Lett. 51, 913 (1987).
- [7] Burrouges H., Bardley J., Brown A., Marks R., Mackay K., Friend R. H., Burns P., Holmes A., Nature 347, 539 (1990).
- [8] Partindge R., Polymer 24, 755 (1983).
- [9] Gymer R., Endeavor 20 (3), 115 (1996).
- [10] Baigert D., Synth. Met. 67, 3 (1994).
- [11] Braun D., Brown A., Slaring E., Meijer E., Synth. Met. 65, 85 (1994).
- [12] Braun D., Hedger A., Appl. Phys. Lett. 58 (1982).
- [13] Braun D., Gustafsson G., McBranch D., Heeger A.J., J. Appl. Phys. 72, 564 (1992).
- [14] Bradley D., Synth. Met. 54, 401 (1993).
- [15] Pei Q., Yu G., Zhang C., Yang Y., Heeger A. J., Science 269, 1086 (1995).
- [16] Kumar P., Jain S. C., Kumar V., Chand S., Kamalasanan M. N., Tandon R. P., J. Phys. D: Appl. Phys. 40, 7313 (2007).
- [17] Shukla M ., Kumar P., Chand S., Brahme N., Kher R. S., Khokhar M. S. K., J. Phys. D: Appl. Phys. 41, 165101 (2008).
- [18] Tang C. W., VanSlyke S. A., Chen C. H., J. Appl. Phys. 65, 3610 (1989).
- [19] Zhang C., Braun D., Heeger A. J., J. Appl. Phys. 73, 5177 (1993).
- [20] Marai F., Romdhane S., Romdhane A., Bourguigua R., Loussaief N., Fave J. L., Synth. Met. 114, 255 (2000).