International Journal of Luminescence and its applications
Volume 4(I), 14/02/2014, ISSN 2277 – 6362

Decay Time of Electroluminescence of Pulsed Organic Light Emitting Diodes

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Abstract

Organic Light Emitting Diode (OLED) is an optoelectronic device in which a single layer, bilayer or multilayer of organic materials is sandwiched between two electrodes, at least one of which is transparent. The working of OLEDs is based on several processes such as charge carrier injection, exciton formation, decay of excitons and light emission. Several transient characteristics such as delay time, rise time and decay time of OLEDs play very important role in understanding the processes involved in the working of OLEDs. When a rectangular voltage pulse of short duration is applied to an OLED, then initially the electroluminescence (EL) intensity increases with time and later on it attains a saturation value. Subsequently, when the applied voltage pulse disappear, the EL intensity decreases with time; either with one decay time or with two decay time involving fast decay and slow decay of EL brightness. In the single layer ITO/MEH-PPV/Ca:Al OLEDs, the fast decay τ_1 and the slow decay τ_2 are found to be 17.67 and 62.5 nanoseconds, respectively. The decay time τ_1 and τ_2 for ITO/BC_ZVBi/Mg:Ag OLEDs are found to be 9.08 and 127.39 nanoseconds, respectively. For ITO/PPV/Al, τ_1 and τ_2 OLEDs are found to be 21.74 and 125.31 microseconds, respectively. For ITO/Alq_3/Mg:Ag, OLEDs, the values of τ_1 and τ_2 are found to be 62.58 and 1492.53 nanoseconds, respectively. For the phosphorescent OLEDs, ITO/6%$Ir(ppy)_3$ in CBP/BCP/ETL/Mg:Ag, the fast decay time τ_1 and slow decay time τ_2 come out to be 3.60 and 12.78 microseconds, respectively. For $\beta(=\frac{1}{\tau_{ex}}) \gg \alpha(=\frac{1}{Cr_d})$, (where C is the capacitance of the OLED and r_d is the differential resistance of the OLED), the decay time gives the time constant of the OLEDs. On the other hand, For $\beta(=\frac{1}{\tau_{ex}}) \ll \alpha(=\frac{1}{Cr_d})$, the decay time gives the lifetime of excitons.

1. Introduction

In the recent past, OLEDs have attracted worldwide attention as a candidate for next generation of flat-panel displays and environmentally friendly solid state lighting devices. Furthermore, the discovery of bright organic electroluminescent diodes has stimulated intense research in order to understand the physics of injection, transport and recombination processes in organic semiconductors. Understanding the time-resolved electroluminescence in OLEDs is of great interest from the physical point of view as well as from the device engineering point of view. Transient electroluminescence means the time-resolved EL after applying a square voltage pulse over the sample. The time-resolved pulsed excitation EL also provides insight into the space charge buildup and carrier transport inside the active semiconducting layer of organic materials. The transient response is also important in the context of possible application of OLEDs in optical communications, where their utility will ultimately be limited by the response of OLED light sources to high frequency modulation. It is to be noted that apart from efficiency and long time stability, the response time of OLEDs when addressed to step-voltage is an essential criterion for their application in optoelectronic displays. The Present paper reports the decay time of electroluminescence in pulsed OLEDs.

2. Theory

The decay of TEL starts from the time t_c, at which the applied voltage pulse starts decreasing. If the relaxation of charges Q across the OLED starts at t = t_c, then, we get, $Q=Q_0\exp[-\alpha(t-t_c)]$, where Q_0 is the charge at t = t_c, and $\alpha = 1/Cr_d$, in which r_d = dV/dj, is the differential resistance of the OLED. The rate of generation of excitons in EML will be proportional to dQ/dt, and therefore, we can write the following equation [1].

$$\frac{dN_{ex}}{dt} = B\alpha Q_0 \exp[-\alpha(t-t_c)] - \frac{N_{ex}}{\tau_{ex}} \tag{1}$$

$$\frac{dN_{ex}}{dt} = B\alpha Q_0 \exp[-\alpha(t-t_c)] - \beta N_{ex}$$

$$\frac{dN_{ex}}{dt} + \beta N_{ex} = B\alpha Q_0 \exp[-\alpha(t-t_c)] \qquad (2)$$

where τ_{ex} is the lifetime of excitons, $\beta = 1/\tau_{ex}$, B is a constant, and N_{ex} is the number excitons at any t time after t_c

Multiplying both side of the Eq. (2) with exp[β(t - t_c)], we get

$$(\frac{dN_{ex}}{dt} + \beta N_{ex})\exp[\beta(t-t_c)] = B\alpha Q_0 \exp[(\beta-\alpha)(t-t_c)] \quad (3)$$

Integrating Eq. (3), we get

$$N_{ex}\exp[\beta(t-t_c)] = \frac{B\alpha Q_0 \exp[(\beta-\alpha)(t-t_c)]}{(\beta-\alpha)} + C \qquad (4)$$

Taking $N_{ex} = N_{ex}^0$, at t = t_c, in Eq. (4), we get

$$N_{ex}^{\ o} = \frac{B\alpha Q_0}{(\beta-\alpha)} + C$$

or,

$$C = N_{ex}^{\ o} - \frac{B\alpha Q_0}{(\beta-\alpha)} \qquad (5)$$

Putting the value of C in Eq. (4), we get

$$N_{ex}\exp[\beta(t-t_c)] = \frac{B\alpha Q_0 \exp[(\beta-\alpha)(t-t_c)]}{(\beta-\alpha)} + N_{ex}^{\ o} - \frac{B\alpha Q_0}{(\beta-\alpha)} \quad (6)$$

Dividing both sides of Eq. (6) by $\exp[\beta(t-t_c)]$, we get

$$N_{ex} = \frac{B\alpha Q_0}{(\beta-\alpha)}\exp[-\alpha(t-t_c)] + N_{ex}^0 \exp[-\beta(t-t_c)] - \frac{B\alpha Q_0}{(\beta-\alpha)}\exp[-\beta(t-t_c)] \quad (7)$$

If η is the efficiency for the radiative decay of excitons, then from Eq. (7) the EL intensity I = $\eta\beta N_{ex}$, is given by

$$I = \eta\beta\left[\frac{B\alpha Q_0}{(\beta-\alpha)}\exp\{-\alpha(t-t_c)\} + N_{ex}^0 \exp\{-\beta(t-t_c)\} - \frac{B\alpha Q_0}{(\beta-\alpha)}\exp\{-\beta(t-t_c)\}\right] \quad (8)$$

Now, the following two cases arise:

Case I: β >> α

For β>>α, Eq. (8) becomes

$$I = \eta D B\alpha Q_0 \exp[-\alpha(t-t_c)] \qquad (9)$$

In this case, the decay time τ_d=1/α=Cr_d, should decrease with increasing voltage as r_d decreases with increasing voltage.

Case II: α>>β

For α>>β, Eq. (8) gives

$$I = \eta\beta N_{ex}^0 \exp[-\beta(t-t_c)] + \frac{\eta\beta B\alpha Q_0}{(\alpha-\beta)}\exp[-\beta(t-t_c)]$$

or, $$\eta[\beta N_{ex}^0 + \beta B Q_0]\exp[-\beta(t-t_c)] \qquad (10)$$

As the rate of generation of excitons at t = t_c, is $B\alpha Q_0$ and lifetime of excitons is 1/β; we get, $N_{ex}^0 = (B\alpha Q_0)/\beta$. Thus, Eq. (10) can be expressed as

$$I = \eta\beta Q_0\alpha\left[1 + \frac{\beta}{\alpha}\right]\exp[-(t-t_c)] \qquad (11)$$

For β >> α, Eq. (11) is given by

$$I = I\exp[-\beta(t-t_c)] \qquad (12)$$

where $I_s = \eta B\alpha Q_0$

Equation (12) indicates that for α >> β, the decay time τ_{ex} = 1/β and thus the decay time of TEL should be equal to the lifetime of excitons, and it should not depend monotonically on the amplitude of the applied voltage pulse.

3. Experimental Support to the Proposed Theory

Fig.1. Shows the semilog plot of EL intensity versus time. In this case [2], the EL decays initially at a fast rate and then at a slow rate.

Fig.2. Shows the semilog plot of the EL intensity versus time for ITO/BC_ZVBi/Mg:Ag [3]. The values of τ_1 and τ_2 for this OLEDs comes out to be 9.08 and 127.39 ns, respectively.

Fig.3. Illustrates the semilog plot of the EL intensity versus time of ITO/PPV/Al [4]. In this case, the values of τ_1 and τ_2 are found to be 21.74 μs and 125.39 μs, respectively.

Fig.4. Illustrates the semilog plot between EL intensity and time for ITO/Alq_3/Mg:Ag [5]. For this OLEDs the value of fast decay time 62.58 ns and the value of slow decay time 1492.53 ns, respectively.

Fig.5. Shows the semilog plot of the EL intensity versus time for ITO/$Ir(ppy)_3$ in CBP/BCP/ETL/Mg:Ag [6]. For this OLEDs the values of τ_1 = 3.60 μs and τ_2 = 12.78 μs, respectively.

Table 1 gives the values of τ_1 and τ_2 for different OLEDs.

Table 1. Values of τ_1 and τ_2 for different OLEDs.

S.No.	Material Name	τ_1 (Fast decay)	τ_2 (Slow decay)
1	ITO/MEH-PPV/Ca:Al	17.67 ns	62.5 ns
2	ITO/BC_ZVBi/Mg:Ag	9.08 ns	127.39 ns
3	ITO/PPV/Al	21.74 μs	125.39 μs
4	[illegible]	[illegible]	1492.53 ns
5	[illegible]	[illegible]	12.78 μs

4. Figure

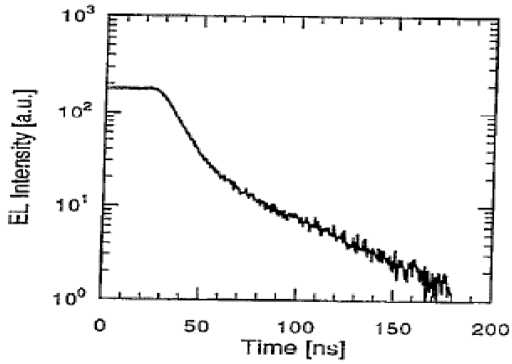

Fig.1 Semilog plot of the EL intensity versus time for ITO/MEH-PPV/Ca:Al of the OLED [2].

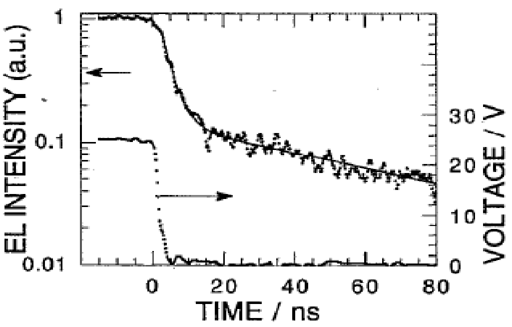

Fig.2 Semilog plot of the EL intensity versus time for ITO/BC_ZVBi/Mg:Ag of the OLED [3].

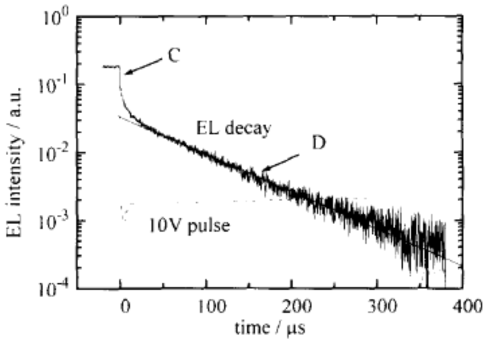

Fig.3 Semilog plot of the EL intensity versus time for ITO/PPV/Al of the OLED [4].

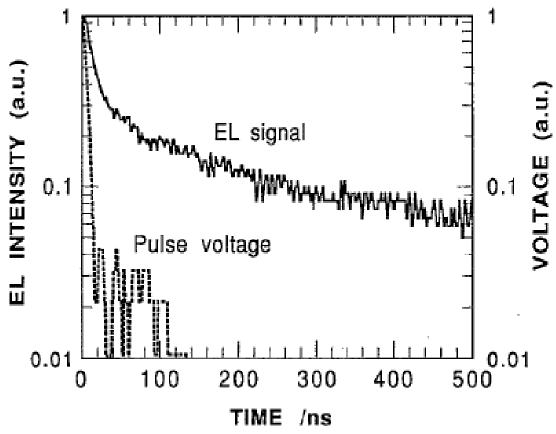

Fig.4 Semilog plot of the EL intensity versus time for ITO/Alq_3/Mg:Ag of the OLEDs [5].

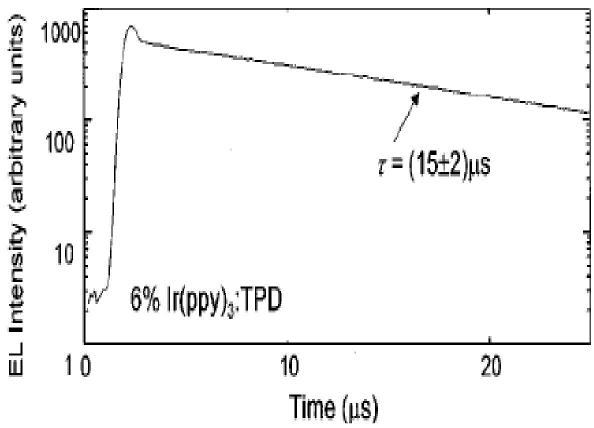

Fig.5 Semilog plot of the EL intensity versus time for ITO/Alq_3/Mg:Ag of the OLED [6].

5. Conclusions

The theoretical studies made for the decay time of EL in pulsed organic light emitting diodes shows that, in general, there should be two decay times; namely the fast decay time τ_1 and the slow decay time τ_2 for OLEDs , in which the decay times are related to the lifetime of excitions and the time constant of the OLEDs, respectively.

Depending on the prevailing conditions any one of these two decay time may be the for fast decay or slow decay. Expressions are derived for the decay times of pulsed OLEDs, in which a good agreement is come between the theoretical and experimental results.

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