Electric Field Dependence of Charge Carrier Injection in OLEDs

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Abstract

The present paper reports that in polymer OLEDs Injection current is a function of electric fields. When the electric field is increased, the efficiency of injection increment will be more significant than in the case when only image force is considered. When the forward field across the 100 nm thin OLED is increased, the triangular energy barrier becomes shallower. It is typically~2 nm wide at an applied field of 2 MV/cm, in which the width is sufficiently thin for tunneling. For a triangular barrier, the Fowler-Nordhium (FN) current density is given by an expression, which is a nonlinear function of field F through the image-force lowering effect. Typically, for low fields (<2 MV/cm), the thermionic current dominates. For high fields (>2MV/cm), the tunneling current prevails. In general, at low field the charge injection in organic light emitting diodes (OLEDs) takes place by thermionic emission process and at high field the charge injection in OLEDs takes place by tunneling process. The processes of charge carrier injection in OLEDs are discussed in detail. The expression for current density j shows that charge injection at low applied bias is primarily due to thermal emission of charge carrier and at high applied bias, it follows Nordiem-Fowler equation.

Key words: triangular energy barrier, image-force lowering effect, dielectric permittivity, tunneling current.

Introduction

Organic light emitting diodes (OLEDs) are electronic devices made by placing a thin film of an electroluminescent organic material between two conductors of different work functions. When an electrical voltage is applied, electrons and holes are injected into the electroluminescent material. When these recombine, light is emitted. The first polymer LED (PLEDs) was fabricated by spin coating a precursor polymer of the luminescent poly-(para-phenlenevinylene) (PPV) onto a indium tin oxide (ITO) coated glass. To overcome this theoretical limit phosphorescent OLEDs were fabricated by doping phosphorescent molecules. Some of the advantages of OLED technology rely on the easiness of chemically modifying the materials, either to tune the colors or to make them processable, through the control of solubility. We have been involved in this research area for several years, either designing and synthesising new materials, or engineering the electrode-polymer interfaces, by inserting appropriate monomolecular layers, in order to improve the luminescence efficiency. New materials have been developed with controlled emission color (for multicolour displays), controlled charge injection, controlled solubility, and controlled inter chain interactions for optimization of luminescence efficiency. The OLEDs have become the most attractive display technology. OLEDs can be used for large and small area flat panel flexible self-luminous displays in many consumer products

The steps involved in the operation of OLEDs are: charge carrier injection, carrier recombination, exciton formation, and decay of excitons. The present paper reports the theory of charge carrier injection in OLEDs and makes a comparison between the theoretical and experimental results.

2. Theory

In OLEDS Charge injection is the process in which the charge carriers enter a material through a surface boundary. This ability is of crucial importance for recombination electroluminescence (REL). Although, for the occurrence of the charge injection the concentration of mobile carriers (n_f) in the surface region should be much larger than that in the bulk of the sample. If the carriers trapped within the sample (n_t) are taken into consideration, the condition for the current to be injection limited (ILC) is that **the capacitor charge related to the unit volume ($\varepsilon\varepsilon_0$F/d)** must be much greater than the average concentration of the total charge in the sample **(n_f+n_t)e**

In OLEDs Junction capacitance $c = \varepsilon\varepsilon_o \frac{A}{d}$

i.e. $q = vc, \Rightarrow q = Fd\, \varepsilon\varepsilon_o \frac{A}{d} = \varepsilon\varepsilon_o AF$

Further, $\frac{q}{V} = \varepsilon\varepsilon_o \frac{AF}{Ad} = \varepsilon\varepsilon_o \frac{F}{d}$ ---- (I)

As current in an OLED is given by $I = nAv_d e$,

But, $v_d = \mu F$

i.e., $I = nAv_d\mu Fe$, but, $j = \frac{I}{A} = \frac{nA\mu Fe}{A} = n\mu Fe$

As, $n = (n_f + f_t)$

$j = \left(\frac{n_f}{n_t}\right) \mu Fen_t$

As, $n_f \gg n_t$ also, $j = \emptyset\mu Fen_t$ As, $\emptyset \cong n_f/n_t$

$Average\ charge\ concentration(en_t) = \frac{j}{\emptyset\mu F}$ ----- (II)

Considering n_t for (ILC), q/V >> average concentration of total charge.in the sample **(n_f+ n_t)e**
As, for ILC, q/V >> average concentration of total charge. So from (I) and (II)

$\varepsilon\varepsilon_o \frac{F}{d} \gg j/\Phi\mu F$ i.e. $J << \varepsilon\varepsilon_o \frac{F^2}{d} \emptyset\mu$

It is clear from Eq. (1) that an ILC will be observed

- Only for relatively low currents at high electric fields with high-mobility carriers
- Large-value dielectric permittivity materials formed into high chemical and structural perfection (large values ofΦ) thin layers.

Mechanisms of charge carrier injections under field-assisted thermionic injection over the image force barrier are discussed here. The current–field characteristics is determined by $j = e\mu n(x)\left(F - \frac{e}{16\pi\varepsilon\varepsilon_0 x^2}\right) - \mu kT\frac{dn(x)}{dx} + j_s(x)$ --------(2)

Field assisted thermionic injection over the image force barrier: Strong gradient $j_s(x)$:

If *Js(x)*is a strongly decreasing function of x, then the solution of high-field regime of equation (2) is [1]

$j = AF^{\frac{3}{4}} \exp[2\left(\frac{\beta e}{kT}\right)^{\frac{1}{2}} F^{\frac{1}{2}}] = AF^{\frac{3}{4}}$ ----- (3)

Field assisted thermionic injection over the image force barrier: The one-dimensional Onsager model:

It was demonstrated that, in this case, the current in OLEDs is the solution of equation (2) for high fields and it is given by

$j = A_0 F^{\frac{3}{4}} \exp\left(a_S F^{\frac{1}{2}}\right)$ ---------- (4)

Cold emission-Tunneling through the triangular barrier:

Two different cases of such an emission can be distinguished, firstly, the tunneling through the triangular barrier

$j = BF^2 \exp\left(-\frac{b}{F}\right)$ ---------- (5)

Secondly, the primary carrier penetration over the image force barrier is given by

$j = j_0 \exp(-\frac{C_0}{F^{\frac{1}{2}}})$ --------- (6)

$\ell_{eh} = \frac{\hbar}{2\sqrt{2}}(m_{eh}^* N)^{-\frac{1}{2}}$

If $\ell_{eh}$is penetration depth of carrier into insulator. Then, emission current is

$j = j_{oq} \exp\left(-\frac{X_m}{l_{eh}}\right) = j_{oq} \exp\left(c_0 - \frac{C_{qeh}}{F^{\frac{1}{2}}}\right)$ ----- (7)

Experimental support:

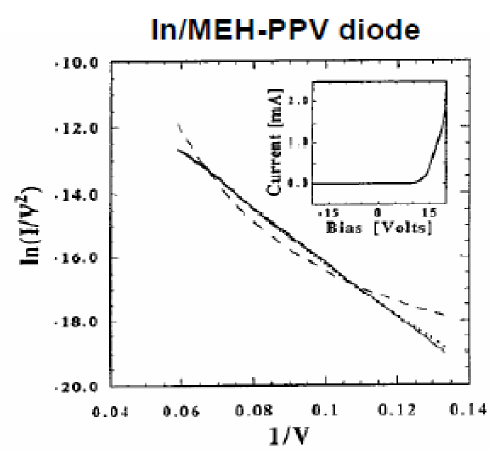

Figure 1 Plot of ln(I/V^2) versus 1/V (Dashed line – thermionic emission, solid line- tunneling)

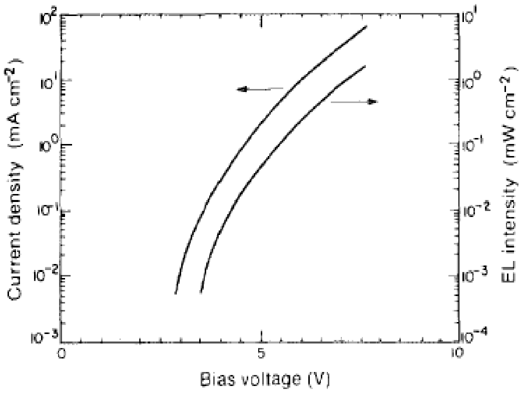

Figure 2. Brightness-current-voltage characteristics of an ITO/diaminei /Alq/MG:Ag EL cell.

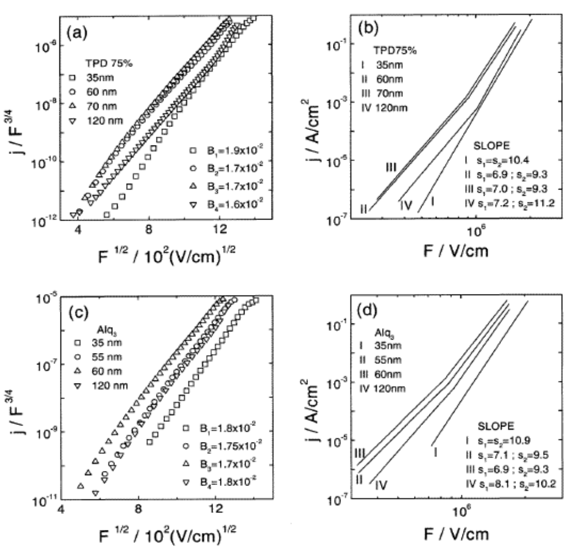

Figure 3 (a, c) The current-field characteristics in log j/F3/4 against F/2 and (b,d) log j against log F representation of ITO/ (PC + 75% TPD)/Alq3/Mg DL LEDs at various thickness of HTL with a constant Alq3 layer thickness d2 D 60 nm (a,b), and of ETL with a constant (PC + 75% TPD) layer thickness d1 D 60 nm (c,d). The thickness and slopes (B in (a) and (c), s1 and s2 in (b) and (d)) of the straight lines approximating the experimental plots are indicated in the figures.

4. Conclusion

Current injection in OLEDS is very important from the basic and applied points of view. Expressions are derived considering different possibilities. A comparison is made between theoretical and experimental results, in which a good agreement was found between theoretical and experimental result.

5. References

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