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ELECTROLUMINESCENCE EFFICIENCY OF BILAYER ORGANIC LIGHT EMITTING DIODES

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ABSTRACT

Bilayer Organic Light Emitting Diodes (OLEDs) consists of two thin organic layers sandwiched between two electrodes, with the structure, ITO (anode)/ hole transporting layer (HTL)/ electron transporting layer (ETL)/Al (cathode). In this paper we assume the analytical model to calculate electroluminescence efficiency of bilayer organic light emitting diodes, considering the influence of introducing LiF insulating buffer layer at metal/organic interface on the barrier height for electron injection. The relations of EL efficiency versus the applied voltage and injection barrier or internal interfacial barrier or the thickness of organic layer are discussed. The present study may be useful for the development of accurate and reliable models for performance, design optimization and increasing efficiency of OLEDs.

KEYWORDS: Electroluminescence efficiency, Interfacial barrier, Injection barrier, bilayer OLEDs.

INTRODUCTION

Organic light emitting diodes (OLEDs) have been the focus of intense study since the last three decades. In this paper we use the analytical model for the injection and recombination profile in EL efficiency of OLEDs (Kim *et al.*, 1996). Insertion of a buffer layer at the interface of a metal cathode and an organic layer was proved to be an effective way for enhancing electron injection and improving EL efficiency of OLEDs (Park *et al.*, 2001). Due to great difference in the energy of organic layer at the lowest unoccupied molecular orbital (LUMO) and the highest occupied molecular orbital (HOMO), there will be a higher energetic barrier for carriers transporting at Organic/Organic interface, and a bilayer OLED can be divided into ETL and HTL. Under the application of proper bias on bilayer OLEDs, holes will be injected from anode into the HTL, and electrons will be injected from cathode into the ETL. HTL is responsible for hole transport and electron blockage, and similarly, ETL is responsible for electron transport and hole blockage. The blockage strength is determined by hole barrier H'_h of hole transferring to ETL or electron barrier H'_e of electron transferring to HTL. Generally, there is a build-up of space charges at the internal interface between the two organic layers, which results in the redistribution of the electric field. The EL efficiency of bilayer OLEDs has been studied theoretically and experimentally by many researchers (Kalinowski *et al.*, 2001), and many meaningful results were obtained. The present theory, based on the influence of LiF insulating buffer layer inserted at metal/organic interface on the barrier height for electrons injection, their relational expressions were given; according to the mechanism of carriers injection and recombination, the EL efficiency model of bilayer OLEDs was established; the dependence of EL efficiency on the applied voltage and the injection barrier or the internal interfacial barrier or the thickness of organic layer was discussed. The present paper reports the EL efficiency of bilayer OLEDs.

1. Mathematical Approach to the EL Efficiency of OLEDs

If η_{inj} is the efficiency for the charge carrier injection and η_R is the efficiency for the carrier recombination an OLED, then the electroluminescence efficiency can be expressed as

$$\eta_{EL} = \eta_{inj}\eta_R \qquad (1)$$

For an OLED the injection efficiency is given by

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$$\eta_{inj} = \frac{J_{ho}}{J_{scl}} x \frac{J_{eo}}{J_{ohmic}} \quad (2)$$

where J_{ho}, (J_{eo}) is the tunneling current density injected by the anode (cathode), J_{scl} is the space charge limited current density for holes injected by anode, and J_{ohmic} is the ohmic current density for the injection from the cathode. The recombination efficiency, η_R of the organic light emitting diode, is given by

$$\eta_R = \frac{J_{rc}}{J_c} \quad (3)$$

where J_{rc} is the total recombination current density in ETL and HTL, J_c is the total cell current density.

As depicted by the shaded area in Fig. 1, in the presence of a LiF layer, the potential barrier (δ_e) for the electron injection tunneling can roughly be regarded as two parts in series, the smaller triangle barrier (denoted by ΔAlq) in the Alq layer and the other (denoted by ΔLiF) induced by the LiF layer. It can be expressed

As $$\Delta = \Delta_{Alq} + \Delta_{LiF} \quad (4)$$

where $$\Delta_{Alq} = \frac{1}{2} A(\phi_{Alq} - F_d L_d)^2 \quad (5)$$

and, $$\Delta_{LiF} = \frac{1}{2} B(\phi_{LiF} - F_d L_d)^2 \quad (6)$$

where *A* and *B* are the fitted constants in the calculation; F_d is the electric field strength in the LiF layer; L_d is the thickness of the LiF layer; Φ_{Alq}, Φ_{LiF} indicates the initial barrier height in the interface LiF/Al and Alq/LiF, respectively. For the case of trap-free materials, J_{scl} is given by Mott-Gurney law:

$$J_{scl} = \frac{9}{8} \varepsilon_0 \varepsilon_r \mu_p \frac{V_h^2}{L_h^3} \quad (7)$$

where ε_0 is the vacuum permittivity, ε_r the relative dielectric constant of the HTL materials, μ_p the hole mobility, V_h is the voltage in HTL, L_h the thickness of HTL. Then J_{ohmic} is depicted as

$$J_{ohmic} = en\mu_n F_e \quad (8)$$

where *e* is the electronic charge *n* is the electron density and μ_n is the electron mobility and F_e is the electric fields in ETL.

The carrier mobilities are field dependent and they may be expressed as

$$\mu_n = \mu_{0n} \exp\left(\frac{F_e}{F_0}\right)^{1/2} \quad \text{and} \quad \mu_h = \mu_{0h} \exp\left(\frac{F_e}{F_1}\right)^{1/2} \quad (9)$$

where μ_{0p}, μ_{0n}, F_0, F_1 are material parameters.

The passage of holes across the internal interface separating hole and electron transporting layers is impeded by an energy barrier H'_h, and similarly, the electron barrier H'_e exists for electron transferring to the hole transporting layer. It is assumed that the internal interface in which the interaction of both organic molecules takes place is very weak, and therefore, it is assumed to be sufficiently thin. Furthermore, the electron transportation can be considered as a hopping process.

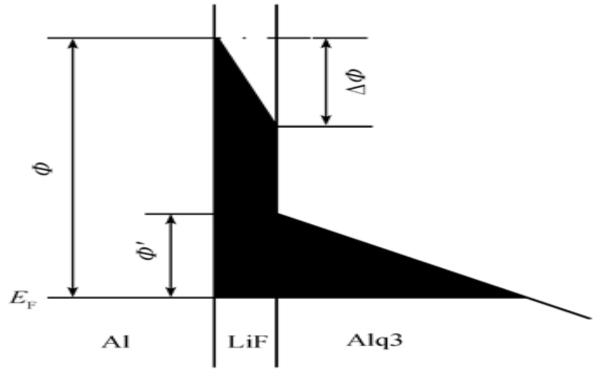

Fig. 1: Schematic diagram of the tunneling model with a LiF buffer layer.

The light emission results from the recombination of charge carriers jumping over the internal interface. At the high electric field, the concept of tunneling through a triangular energy barrier is, nevertheless, a useful first-order approach to describe the injection process. The leakage currents of holes J'_h and electrons J'_e across the internal interfaces described by the Fowler-Nordheim expression are

$$J'_h = \nu_0 \Sigma_h \exp\left(-\frac{\delta'_h}{F_e}\right) \quad (10)$$

and,

$$J'_e = \nu_0 \Sigma_e \exp\left(-\frac{\delta'_e}{F_h}\right) , \quad (11)$$

where $\sum_h$ and $\sum_r$ are the area densities of holes and electrons at the interface, respectively, v_0 is an escape frequency, Δ'_h and Δ'_e are related to the zero field barrier heights (H′) by

$$\Delta' = \frac{4}{3}\frac{(2m^*)^{1/2}}{\hbar e} H'^{3/2} \quad (12)$$

The recombination current can be expressed as

$$J_{rc} = J_{rh} + J_{re} \quad (13)$$

It is known that (Yang et al. 2001)

$$J_{rh} = \sigma_h \sum{}_e J'_e \quad (14)$$

$$J_{re} = \sigma_e \sum{}_h J'_h \quad (15)$$

where σ_h and σ_e are the recombination cross-sections for holes and electrons, respectively. When neglecting the increase of r/μ occurring in hopping systems at very high fields, the recombination cross-section σ can be expressed as (Albrecht et al. 1995)

$$\sigma_e = \frac{r}{\mu_e F_e} = \frac{e}{\varepsilon_0 \varepsilon F_e} \quad (16)$$

and,

$$\sigma_h = \frac{r}{\mu_h F_h} = \frac{e}{\varepsilon_0 \varepsilon F_h} \quad (17)$$

where r is the recombination coefficient of the carriers.

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The applied voltage is distributed between HTL, ETL and the insulating buffer layer and it can be expressed as

$$V = F_e L_e + F_h L_h + F_d L_d \tag{18}$$

where F_e and F_h are related to the interfacial charge densities by the Poisson equation (assuming $\varepsilon_e = \varepsilon_h = \varepsilon$).

$$F_e - F_h = \frac{e}{\varepsilon_0 \varepsilon}\left(\sum{}_h - \sum{}_e\right) \tag{19}$$

Under the steady-state condition, the total current density is determined by the injection current, the leakage current and the recombination current, that is,

$$J_c = J_{h0} + J'_e - J_{rh} = J_{e0} + J'_h - J_{re} \tag{20}$$

CONCLUSION

An analytical model to calculate electroluminescence (EL) efficiency of bilayer organic lightemitting devices, considering the influence of introducing LiF insulating buffer layer at metal/ organic interface on the barrier height for electrons injection, was presented. The relations of EL efficiency versus the applied voltage and injection barrier or internal interfacial barrier or the thickness of organic layer were discussed. The calculated results indicate that M/O interfacial barrier, internal interfacial barrier and the thickness variation of ETL and HTL have an effect on carriers' injection and recombination and EL efficiency to some extent.

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