Available online at www.sciencedirect.com
SCIENCE DIRECT®
Organic Electronics 6 (2005) 92–96
Organic Electronics
www.elsevier.com/locate/orgel

The effect of doping iodine on organic light-emitting diode

S.F. Chen, Y.K. Fang *, S.C. Hou, C.Y. Lin, C.S. Lin, W.R. Chang, T.H. Chou

VLSI Technology Laboratory, Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, No. 1, University Road, P.O. Box 7-200, Tainan, Taiwan

Received 26 August 2004; received in revised form 2 November 2004; accepted 11 March 2005
Available online 7 April 2005

Abstract

The performances of organic light-emitting diodes (OLEDs) with the configuration Al/Alq_3 (Aluminum Tris-(8-hydroxygninoline))/TPD(N,N′-diphenyl-N,N′bis-(3-methylphenyl)-1,l′-bipheny-4,4′-diamine)/ITO have been significantly improved by doping iodine (I_2) on both Alq_3 and TPD layers. The luminance is promoted from 2800 cd/m^2 without doping to 8000 cd/m^2 with I_2 doping under bias 10 V. Additionally, the driving voltage (@100 cd/m^2) was reduced from 7.5 V without doping to 5.2 V with I_2 doping. We attribute the promotions to the reduction of the electron and hole injection energy barrier at Al/Alq_3 and TPD/ITO interfaces and the expansion of trap energy states beneath the LUMO of Alq_3 generated by I_2 doping. The mechanism is illustrated comprehensively with a schematic energy diagram model and nicely supported with photoluminescence (PL), electroluminescence (EL) spectra and other experimental results.

Keywords: Organic light-emitting diodes (OLEDs); Turn on voltage; Driving voltage; Photoluminescence (PL); Electroluminescence (EL)

1. Introduction

Organic light emitting diodes (OLED) have been widely applied on cell phone display, liquid-crystal-display and television for the advantages of low power dissipation, wider vision angle, high luminescence, shorter response time and simplified fabrication [1]. In the past, the technologies to improve the performances, such as electroluminescence efficiency and driving voltage, have been concentrated on lowering barrier height on metal contact [1,2], using high luminescence organic materials [1,3–7] and buffer layer or inter-layers [8–12]. Even these technologies could enhance the performance of OLED, however they also complicate the fabrication process or need some special doping materials [13]. Therefore, there are still

* Corresponding author. Tel.: +886 6 2080398; fax: +886 6 2345482.
E-mail address: ykfang@eembox.ee.ncku.edu.tw (Y.K. Fang).

1566-1199/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.orgel.2005.03.004

needed the simpler methods or more common doping materials.

In general, for the bi-layer OLED as shown in the inset of Fig. 1, Al/Alq_3 (Aluminum Tris-(8-hydroxygninoline))/TPD(N,N′-diphenyl-N,N′bis-(3-methylphenyl)-1,1′-bipheny-4,4′-diamine)/ITO is adopted to study for its simple structure, where Alq_3 and TPD are electron transport layer (ETL) and hole transport layer (HTL), respectively [14]. To reduce the driving voltage, the common approach is to lower the barrier at Al/Alq_3 interface, for the barrier of Al/Alq_3 contact is larger than the barrier of TPD/ITO [15] and the current is controlled by electrons injection into Alq_3 [16]. In other word, lowering Al/Alq_3 barrier is more effective than lowering the TPD/ITO barrier [17–19]. On the other hand, it has been evidenced that the incorporation of iodine (I_2) on organic material could increase the conductivity [20]. Hence, in this study, we lowered Al/Alq_3 barrier with doping iodine on ETL and improve the output luminance by doping iodine (I_2) on both ETL and HTL layer simultaneously. The doped I_2 molecules on ETL layer generate traps states beneath the lowest unoccupied molecular orbital (LUMO) of Alq_3 [15,21], thus expanding the excited band of LUMO and lowering the Al/Alq_3 barrier for electron to inject. Compared to the reported methods [1–12], the technique possesses the advantage of low cost, convenience and be compatible to the current OLEDs fabrication process. Furthermore, a schematic energy diagram model has been employed to illustrate the improving mechanism comprehensively.

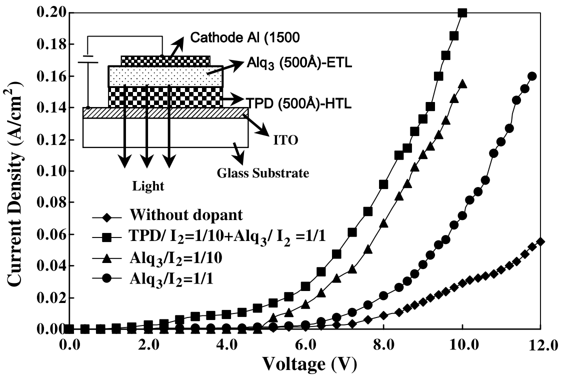

Fig. 1. The J/V curves of bi-layer OLEDs with Alq_3 or both Alq_3 and TPD simultaneously doped with doping different I_2 in weight ratio. The insert presents schematic structure diagram of OLEDs.

2. Device design, fabrication and measurement

The bi-layer OLEDs samples with the configuration of Al/Alq_3/TPD/ITO, as schematically described in the inset of Fig. 1, were prepared in the glass substrates pre-coated by indium tin oxide (ITO) with sheet resistance $R_s \leqslant 10\ \Omega$/square and work function of 4.9 eV. After ultrasonic cleaning in H_2O–H_2O_2–NH_3OH solution, the substrates were taken into a stain steel chamber which then be evacuated to 1×10^{-5} Torr to deposit TPD as HTL. The thickness of TPD layers is 500 Å. Next, Alq_3 with thickness of 500 Å as ETL and Al with thickness of 1500 Å as cathode were evaporated sequentially in the chamber with 1×10^{-5} Torr. In this work, OLED samples were doped I_2 by evaporation of Alq_3 on ETL with various weight ratios I_2 powder (i.e. $Alq_3/I_2 = 1/1$, 1/10) and on HTL by evaporation of TPD with weight ratio of 10/1 I_2 powder (i.e. TPD/I_2 = 1/10) respectively. On the other hand, HP4156 and TOPCON BMP were used to measure the electrical characteristics and output luminance, respectively. Additionally, the photoluminescence (PL) and electronluminescence (EL) were measured with Fluorolog-3 Fluorescence on device samples.

3. Results and discussion

Fig. 1 gives the measured current density–voltage (J/V) curves with various weight ratios as parameter. With doping I_2 (i.e. $Alq_3/I_2 = 1/1$), the current densities of OLED are improved in comparison to that without doping especially under large bias. Also, the improvement is enhanced with increase of dopant weight ratio, i.e., $Alq_3/I_2 = 1/10$ is better than $Alq_3/I_2 = 1/1$. For example, the current density with $Alq_3/I_2 = 1/10$ doping increases to 67 mA/cm^2 and 155 mA/cm^2 from 9 mA/cm^2 and 29 mA/cm^2 for OLED without dopant under 8 V and 10 V biases, respectively. We attribute the increase of current density to the lowering of