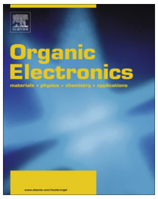
Organic Electronics 22 (2015) 69–73

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel



Enhanced stability in inverted simplified phosphorescent organic light-emitting devices and its origins

Yingjie Zhang *, Hany Aziz

Department of Electrical and Computer Engineering & Waterloo Institute for Nanotechnology, University of Waterloo, 200 University Avenue West, Waterloo, Ontario N2L 3G1, Canada

ARTICLE INFO

Article history:
Received 30 January 2015
Received in revised form 14 March 2015
Accepted 24 March 2015
Available online 25 March 2015

Keywords:
PHOLEDs
Inverted architecture
Enhanced lifetime
e/h ratio
Exciton–polaron interactions

ABSTRACT

We study the stability of simplified phosphorescent organic light-emitting devices in standard and inverted architectures. Results show that the inverted devices have higher electroluminescence stability, exhibiting almost three times longer lifetime relative to the widely used standard device architecture, while having the same current efficiency. Investigations reveal that inverted devices have a higher electron/hole ratio in the hole transport layer and a lower concentration of un-recombined positive charges in the emission layer. The results suggest that their higher stability is due to reduced degradation at the emission layer/electron transport layer interface as a result of reduced exciton–polaron interactions.

1. Introduction

Organic Light Emitting Devices (OLEDs) are currently being utilized for several commercial applications including flat panel displays and solid-state lighting. In general, an OLED consists of a number of organic semiconductor layers interposed between two electrodes, with the whole stack laid on a substrate. In the vast majority of OLEDs, the bottom electrode (i.e. the one adjacent to the substrate) functions as a hole injection anode with the other electrode functioning as an electron injection cathode. Recently, an inverted device architecture in which the functionality of the electrodes is inverted (i.e. the bottom and top electrodes function as cathode and anode, respectively) has gained much interest in the field. This is motivated by two major advantages that the inverted structure has (i) compatibility with the inexpensive n-channel a-Si thin film transistors (TFTs) used in active matrix displays [1–3], and (ii) potentially higher light outcoupling efficiency in top-emitting configuration [4–6]. As a result, a growing body of research has been focusing on phosphorescent OLEDs (PHOLEDs) with inverted architecture recently, with the purpose of improving their efficiency. Surprisingly, the stability of inverted PHOLEDs has not been systematically studied to date, despite being an equally important aspect of OLED performance.

In 2011, the simplified PHOLED structure was introduced by Helander et al. [7]. By utilizing the same material for both the hole transport layer (HTL) and the emitter layer host, efficiency comparable to that of p-i-n PHOLEDs [8] yet with much simpler device structure can be achieved. In addition to simpler fabrication, efficiency roll-off is also greatly improved. However, one issue for such device is its shorter lifetime [9].

In this work, we show that the lifetime of an inverted simplified PHOLED is three times longer than that of a standard simplified PHOLED while having similar current efficiency. The underlying mechanism for the difference in stability is also studied. Results show that inverted devices have higher electron/hole (e/h) ratio, resulting in less positive polarons at the emission layer/electron transport layer interface, thus reduced interfacial degradation.

2. Experimental

In this work, simplified PHOLEDs [7] consisting 4,4′-bis(carbazol-9-yl)biphenyl (CBP) as the HTL and host, 2,2′,2″-(1,3,5-benzinetriyl)-tris(1-phenyl-1-H-benzimidazole) (TPBi) as the electron transport layer (ETL) and tris(2-phenylpyridine)iridium(III) ($Ir(ppy)_3$) and bis(2-phenylpyridine)(acetylacetonate)iridium(III) ($Ir(ppy)_2(acac)$) as the emitters are fabricated and tested. Iridium(III) bis[4,6(difluorophenyl)pyridinatoN,C^2] picolinate (FIrpic) is used to dope into the HTL and the ETL as a marking layer. CBP and TPBi are obtained from Shanghai Han Feng Chemical Co. The iridium-based complexes are obtained from Luminescence

---

* Corresponding author.

E-mail address: y299zhan@uwaterloo.ca (Y. Zhang).

http://dx.doi.org/10.1016/j.orgel.2015.03.033
1566-1199/

Technology Corp. All materials are used as received without further sublimation. Prior to device fabrication, the ITO coated glass substrates are sonicated in acetone and isopropanol for 5 min each, in respective order. Devices are then fabricated in an Angstrom Engineering EvoVac system. All materials are thermally evaporated at a rate of 0.1–2 Å/s at a base pressure of 5×10^{-7} torr. All electrical stress tests are performed under a current density of 20 mA/cm^2 using a Botest OLT lifetime test system. The devices are kept in a N_2 environment during all measurements.

3. Results and discussion

First, to compare the performance of simplified PHOLEDs in standard and inverted architectures, we fabricated devices of the structures presented in Fig. 1: standard device A – ITO/MoO_3 (5 nm)/CBP (25 nm)/CBP:Ir(ppy)$_3$ (5%) (15 nm)/TPBi (35 nm)/LiF (1 nm)/Al (80 nm) and inverted device B – ITO/Mg (5 nm)/TPBi (35 nm)/CBP:Ir(ppy)$_3$ (15 nm)/CBP (30 nm)/MoO_3 (5 nm)/Al (80 nm). We would like to point out that several electron injection layers (EILs) including Mg, LiF, $LiNH_2$ and $CsCO_3$ have been tested in the inverted device. Mg is chosen due to its good deposition reproducibility, which gives a more consistent device performance. The use of slightly different CBP layer thicknesses in the two structures is to achieve optimal efficiency in each case. In the standard architecture, optimizing the CBP thickness is mainly for adjusting charge balance; whereas in the inverted architecture, optimizing the CBP thickness is primarily for adjusting microcavity effects since it separates the emission zone from the reflective metal contact [10]. Fig. 2(a) presents the current density vs. voltage characteristics of these devices. It can be seen that the inverted device has a higher driving voltage, which can be attributed to the use of a thicker organic stack as well as an EIL with a deeper work function (3.7 eV for Mg vs. 2.6 eV for LiF), hence the presence of a higher injection barrier. Despite the difference in driving voltages, both devices demonstrate similar current efficiency, as shown in Fig. 2(b), suggesting that the exciton density in the emission layers (EMLs) of the two devices must be comparable. It is important to note that the efficiency roll-off behavior in these devices is dominated by host–host triplet–triplet annihilation as opposed to triplet polaron quenching, as shown by our previous studies [11]. Given the similar exciton density in the EML, it is not surprising that both devices also exhibit similar efficiency roll-off. The electroluminescence (EL) stability of these devices is tested by measuring luminance over time while the devices are electrically driven at a constant 20 mA/cm^2 current density. Fig. 2(c) presents the normalized luminance (luminance/initial luminance) of these devices over

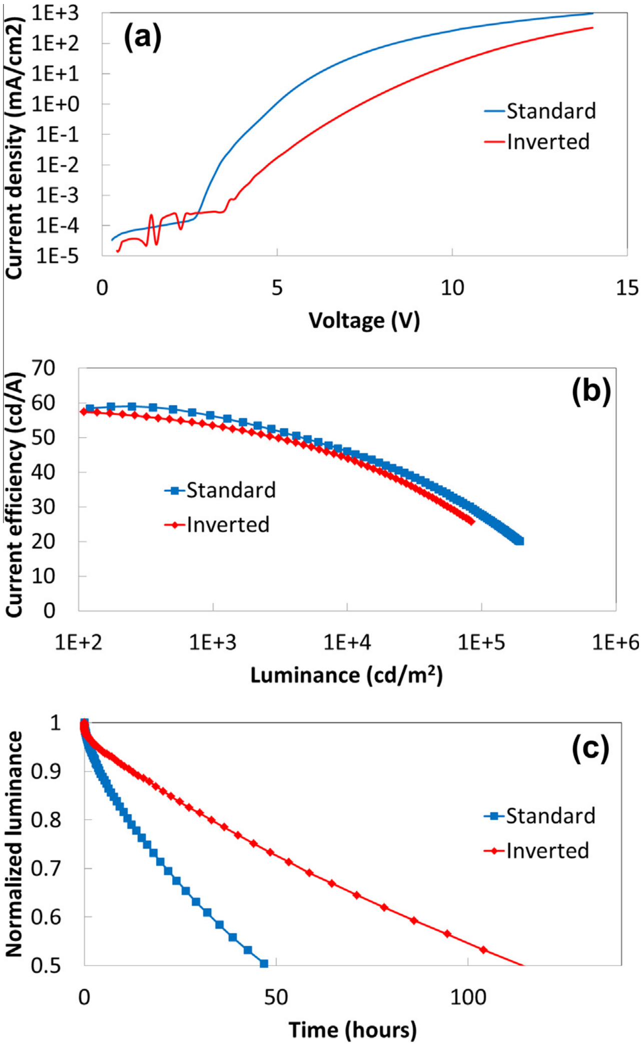


Fig. 2. (a) JV characteristics, (b) current efficiency and (c) lifetime comparison of standard and inverted simplified PHOLEDs.

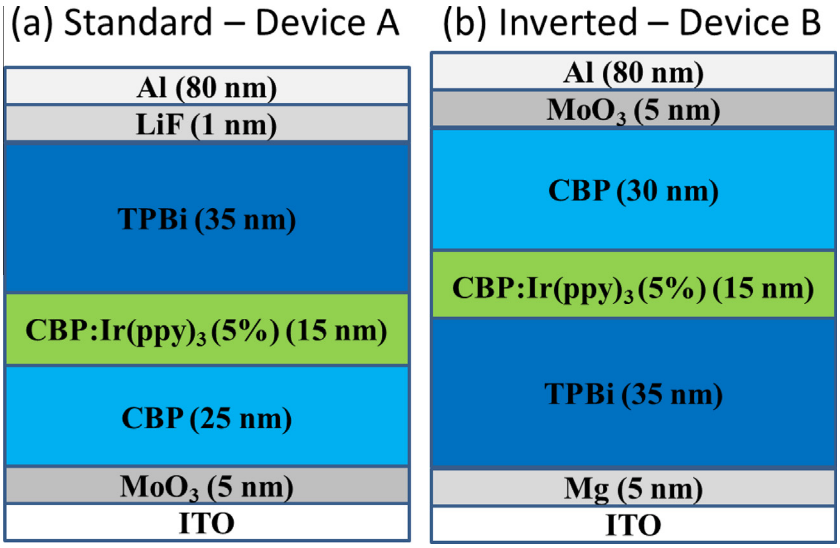


Fig. 1. Device structures of simplified PHOLEDs in (a) standard and (b) inverted architectures.