Current Applied Physics 11 (2011) 311–314

Contents lists available at ScienceDirect

Current Applied Physics

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

High efficiency green phosphorescent OLEDs with triplet exciton confinement architecture

Woo Sik Jeon, Chandramouli Kulshreshtha, Jae Hyung Yu, Myung Jin Lim, Jung Soo Park, Jang Hyuk Kwon*

Department of Information Display, Kyung Hee University, Dongdaemoon-gu, Seoul 130-701, Republic of Korea

ARTICLE INFO

Article history:
Received 25 February 2010
Accepted 20 July 2010
Available online 27 July 2010

Keywords:
Phosphorescent
OLED
Green
Exciton
Triplet

ABSTRACT

We report highly efficient green phosphorescent devices comprising a triplet exciton confinement configuration, using 4,4′-N,N′-dicarbazoleterpheyl (CTP) as a narrow band-gap host and high triplet energy charge transporting layers. Maximum current and power efficiencies of 56.89 cd/A, and 48.22 lm/W (external quantum efficiency of 18.0%) are demonstrated by optimizing the doping concentration. Such high efficiency is attributed to good confinement effect of triplet excitons by narrow band-gap CTP host with reasonable doping concentration and introduction of good exciton blocking layers at the emitting layer interfaces.

1. Introduction

Organic light emitting devices (OLEDs) have been commercialized to mobile flat panel displays while keeping tremendous achievements in this application [1]. OLEDs have also attracted considerable attention for other potential applications such as backlighting, next generation lighting, [2,3] and flexible displays. An indispensable requirement for these applications is their high efficiency characteristics. In order to achieve high efficiency in OLEDs, various approaches, such as use of highly efficient (high luminescence quantum efficiency) organic materials, insertion of excition blocking layer and/or hole and electron blocking layers, and optimization of the doping concentration of OLEDs to reduce self-quenching, have been reported [4–6]. Generally, wide band-gap materials as a host are very common in phosphorescent OLEDs (PHOLEDs), owing to consideration of lower triplet state than singlet one. The spin exchange energy from singlet to triplet state in general organic materials is very high, as over 0.5 eV [7,8]. Such high exchange energy in the devices increases the voltage with decrease in efficiency. When wide band-gap host is used as a host material in the emitting layer, carrier mobility decreases significantly, because dopant molecules act as charge trapping sites [9]. To overcome such problem, high doping concentration of over 7% in green PHOLEDs is required to make a good balanced of current flow through dopant molecule connections. In such devices, exciton self quenching and triplet–triplet annihilation by high doping concentration are inevitable problems. When the doping concentration is increased from 2 to 6%, the phosphorescence photoluminescence quantum efficiency of tris(2-phenylpyridine)iridium ($Ir(ppy)_3$) is decreased by ~5% [10]. In addition, good exciton confinement structures are very difficult with wide band-gap host materials in the PHOLED devices. To overcome these constraints, a narrow band-gap host of 4,4′-N,N′-dicarbazoleterpheyl (CTP) was developed by our group [11]. In this study, we report highly efficient green phosphorescent devices comprising a triplet exciton confinement configuration using our CTP host with high triplet energy charge transporting layers. The maximum current and power efficiencies of 56.89 cd/A, and 48.22 lm/W with 18% external quantum efficiency are realized by this good triplet exciton confinement configuration by minimization of self quenching.

2. Experiment

α-NPB (N,N′-Bis(naphthalen-1-yl)-N,N′-bis(phenyl)benzidine) and TCTA (4,4′4″-tris(N-carbazolyl)-triphenylamine) were used as a hole injection and hole-transporting layers to make green PHOLEDs. “The CTP and $Ir(ppy)_3$ were used as a host and green dopant and, BAlq (aluminum (III) bis(2-methyl-8-quinolinato)-4-phenylphenolate) as hole blocking layer” to "The CTP, $Ir(ppy)_3$, and BAlq (aluminum (III) bis(2-methyl-8-quinolinato)-4-phenylphenolate) were used as a host, green dopant, and hole blocking layer, respectively”. To fabricate OLED devices, clean glass substrates

* Corresponding author. Tel.: +82 2 961 0948; fax: +82 2 961 9154.
E-mail address: jhkwon@khu.ac.kr (J.H. Kwon).

1567-1739/$ – see front matter
doi:10.1016/j.cap.2010.07.024

precoated with a 150-nm-thick indium tin oxide (ITO) layer and a sheet resistance of ~20 Ω/sq were used. Line patterns of ITO were formed on glass by photolithography process. The ITO glass was cleaned by sonification in an isopropylalcohol and acetone, rinsed in deionized water, and finally irradiation in a UV–ozone chamber. All organic materials were deposited by the vacuum evaporation technique under a pressure of $\sim 2.0 \times 10^{-7}$ Torr. The deposition rate of organic layers was about 0.5 A/s. Subsequently, LiF and Al were deposited in another vacuum deposition system without breaking vacuum. Deposition rates of LiF and Al were 0.1 A/s and 5–10 A/s, respectively. The active area was 2×2 mm^2 for all the samples. The current density-voltage (J–V) characteristics were measured by Keithley 2635 A and luminance–voltage (L–V) characteristics were measured by Minolta CS-1000A, respectively.

3. Results and discussion

In order to make a triplet exciton confinement configuration in green PHOLEDs, triplet energies among various hole-transporting and electron transporting materials were investigated. The triplet energies (T_1) of NPB, TCTA, BAlq, and Bphen are about 2.3, 2.7, 2.2, and 2.5 eV, respectively [12–14]. Fig. 1(a) shows emission spectra of CTP at room temperature and 77 K low temperature and phosphorescence spectrum of Ir(ppy)$_3$ at room temperature. CTP exhibited triplet energy of 2.5 eV, obtained from the first phosphorescent peak at 491 nm, while Ir(ppy)$_3$ dopant shows its triplet energy at 2.4 eV. Fig. 1(b) shows all the triplet energy levels of used materials. The LUMO (lowest unoccupied molecular orbital) of NPB and HOMO (highest occupied molecular orbital) values of BAlq are 2.3 eV and 6.0 eV, respectively which make them as a good electron and hole blocking layer materials. However, their low triplet energies as 2.3–2.2 eV may results some quenching of triplet excitons at the emitting layer interface [9]. To investigate triplet exciton confinement ability, five devices are designed as follows:

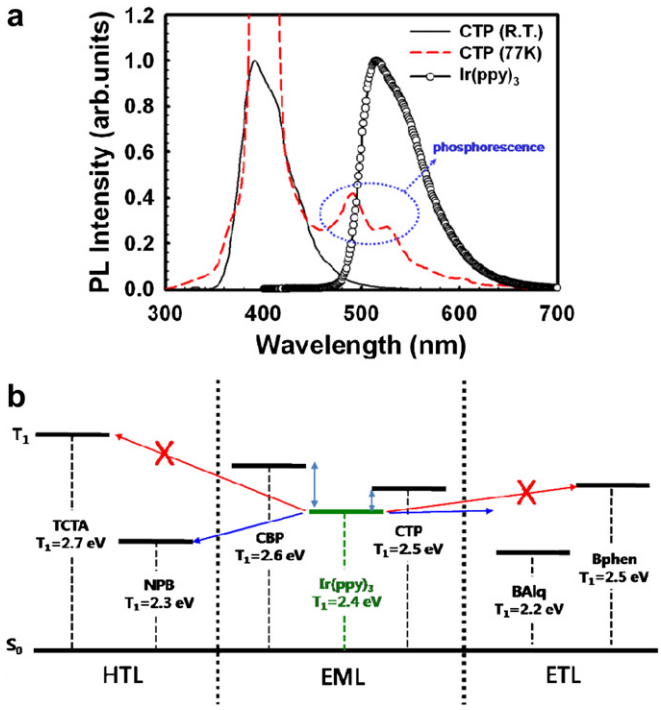

Fig. 1. (a) Emission spectra of CTP and Ir(ppy)$_3$, (b) Triplet energy levels of used materials for green PHOLEDs.

Device A: ITO/NPB (40 nm)/CTP: Ir(ppy)$_3$ (8 wt%, 30 nm)/BAlq (5 nm)/Alq$_3$ (20 nm)/LiF (0.5 nm)/Al (100 nm);
Device B: ITO/NPB (30 nm)/TCTA (10 nm)/CTP: Ir(ppy)$_3$ (8 wt%, 30 nm)/Bphen (25 nm)/LiF (0.5 nm)/Al (100 nm);
Device C: ITO/NPB (30 nm)/TCTA (10 nm)/CTP: Ir(ppy)$_3$ (5 wt%, 30 nm)/Bphen (25 nm)/LiF (0.5 nm)/Al (100 nm);
Device D: ITO/NPB (30 nm)/TCTA (10 nm)/CTP: Ir(ppy)$_3$ (3 wt%, 30 nm)/Bphen (25 nm)/LiF (0.5 nm)/Al (100 nm);
Device E: ITO/NPB (30 nm)/TCTA (10 nm)/CTP: Ir(ppy)$_3$ (1 wt%, 30 nm)/Bphen (25 nm)/LiF (0.5 nm)/Al (100 nm).

Device A, having a conventional device structure was fabricated as the control sample. Device B was made as a triplet exciton confinement configuration. J-V-L and efficiency versus luminance characteristics were measured over brightness of 10 000 cd/m^2 and are displayed in Fig. 2 (a) and (b), respectively. The driving voltage to reach 1000 cd/m^2 is 6.5 V. The current and power efficiencies of 21.93 cd/A and 10.82 lm/W at a brightness of 1000 cd/m^2 are obtained in a control Device A, respectively. In Device B, the low driving voltage of 4.7 V was noticed which could be because of resistance reduction of CTP through good carrier injection, and movement by a narrow band-gap host as well as of good electron transporting performance of Bphen. The CTP had been reported as a good triplet green host and its exchange energy (from S_1 to T_1) is small as 0.3–0.5 eV. [11] As our expectation, Device B shows good current and power efficiencies of 39.84 cd/A and 36.63 lm/W at a brightness of 1000 cd/m^2, respectively. Its performance is still not considered up to the mark for considering good triplet excitons confinement configuration in the emitting layer. Very low current efficiency roll-off of 5% over the brightness of 10 000 cd/m^2 is

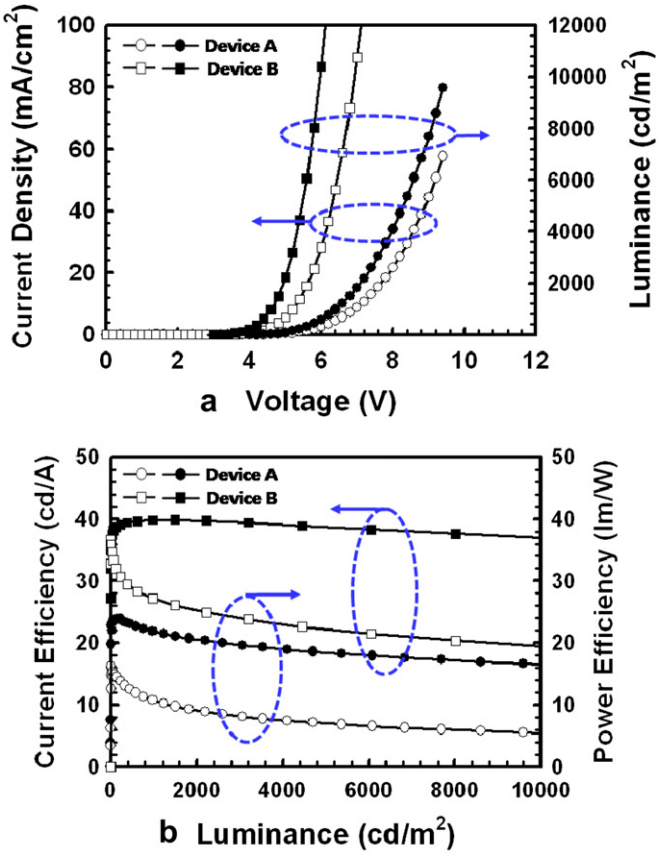

Fig. 2. J-V-L and Efficiency characteristics of Device A and B. (a) J-V-L characteristics, (b) L vs. current and power efficiencies characteristics.