Low operating voltage and long lifetime organic light-emitting diodes with vanadium oxide (V_2O_5) doped hole transport layer

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Abstract

We report low operating voltage and long lifetime organic light-emitting diodes (OLEDs) with a vanadium oxide (V_2O_5)-doped N,N'-di(1-naphthyl)-N,N'-diphenylbenzidine (α-NPD) layer between indium tin oxide and α-NPD. At a luminance of 1000 cd/m^2, V_2O_5 doped α-NPD device shows a operation voltage of 5.1V, while the device without V_2O_5 shows 5.8V. The V_2O_5 doped α-NPD device also shows a longer lifetime and smaller operation voltage variation over time. It is suggested that the improved device performance can be attributed to the higher hole-injection efficiency and stability of the V_2O_5–doped α-NPD layer.

1. Introduction

Organic light-emitting diodes (OLEDs) emerge as a new flat-panel display technology with superior display qualities since the first demonstration of efficient light emission by C. W. Tang [1], intensive researches have been carried out to improve the device performances such as luminous efficiency, driving voltage and lifetime [2, 3]. Since the light-emission in OLEDs depends on the injection and recombination of electrons and holes, it is very important to enhance carrier injection efficiency and electron-hole balance for obtaining low operating voltage and high efficiency [4, 5]. However, the work function difference between electrode and organic materials results in a potential energy barrier which limits the carrier injection at organic/electrode interfaces [14]. One way to improve the carrier injection is the insertion of an appropriate carrier injection layer which leads to effectively lower potential barrier. At the interface of the transparent indium tin oxide (ITO) and the hole-transport layer (HTL), various materials such as copper phthalocyanine (CuPC) [6, 13], or 4,4', 4"-tris{N, (3-methylphenyl)-N-phenylamino} -triphenylamine) (m-MTDATA) [7] or conducting fluorocarbon coatings (CF_x) [12] are often used and found to enhance quantum efficiency and the durability of the OLEDs.

Nowadays, transition metal oxides emerges as a new candidate for hole injection and transport material in OLEDs and organic photovoltaic cells [8-10]. Especially, vanadium oxide (V_2O_5) is usually used in tandem OLEDs as a charge generation layer [11]. In this letter, we report a low operation voltage and long lifetime OLEDs with V_2O_5 doped HTL.

2. Results

We have fabricated the OLEDs with *N,N'-di(1-naphthyl)-N,N'-diphenylbenzidine (α-NPD)* hole transport layer, *tris*(8-hydroxyquinoline) aluminum (Alq_3) electron transport layer, and LiF/Al cathode. The substrate is a pre-patterned indium-tin-oxide (ITO). It was cleaned by ultrasonication in isopropyl alcohol, acetone, and methanol for 10 minutes, respectively and rinsed in de-ionized (DI) water for 5 minutes between several cleaning steps. And ITO substrate was dried in an oven kept at 120°C for more than 30 minutes. After cleaning and drying, the ITO substrate was treated with ultraviolet ozone (UVO) for 4 minutes. Then the organic layers and cathode were all deposited under the high vacuum ($< 3 \times 10^{-6}$ Torr) without breaking vacuum. The active area of the OLED, defined by the overlap of the ITO and the AL cathode, was 1.96 mm^2. The deposion rates for the organic layers were 0.1~0.2 nm/sec and 0.3~0.4 nm/sec for metal. The current-voltage-luminance (I-V-L) characteristics were measured with a Keithley 236 source-measure unit and a Keithley 2000 multimeter equipped with a PMT through an ARC 275 monochromator. The external quantum efficiency (QE) of the electroluminescence (EL), defined as the ratio of the emitted photons to the injected electric charges, was calculated from the EL intensity measured by the calibrated Si photodiode placed at the normal angle to the device surface, while assuming that the device is a Lambertian source.

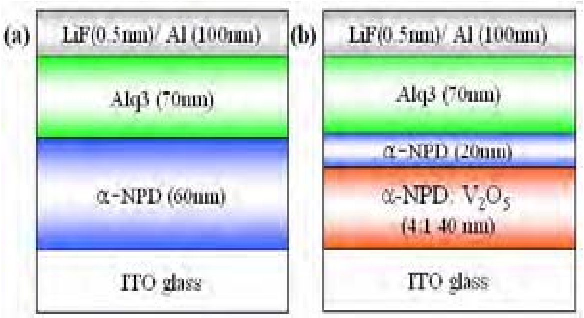

Figure 1. The device structure of reference (a), and V_2O_5 doped α-NPD device (b)

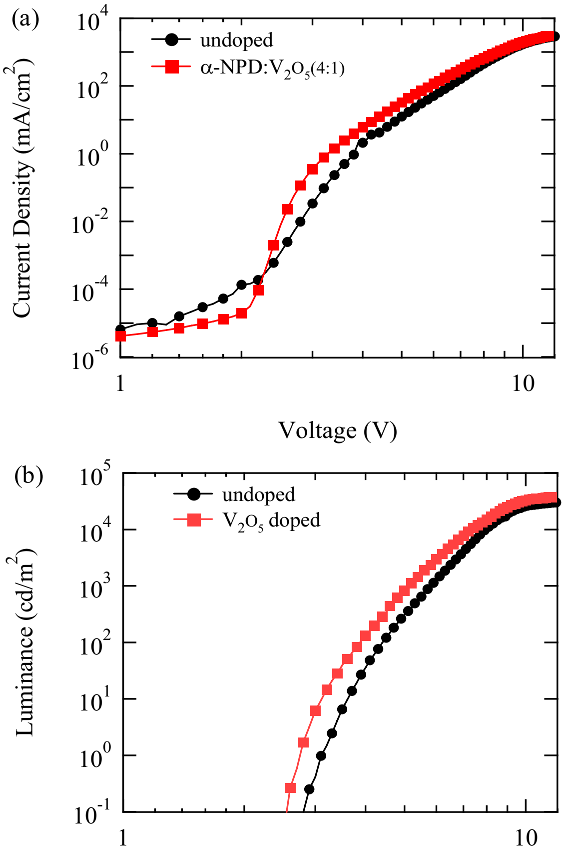

Figure 2. The current density-voltage (a) and luminance-voltage (b) characteristics

Fig. 1-(a) is a reference device structure. The hole transport layer (α–NPD, 60 nm), emitting and electron transport layer (*tris*(8-hydroxyquinoline) aluminum; Alq_3, 70 nm), and LiF (0.5 nm)/Aluminum (100 nm) cathode is thermally evaporated sequentially without breaking vacuum. Fig. 1-(b) shows the device structure with V_2O_5 doped HTL; the thickness of doped layer is 40 nm and the ratio of α–NPD to V_2O_5 is 4:1. The α–NPD layer of thickness 20 nm between the doped hole transport layer and emitting layer is necessary to prevent the V_2O_5 molecules from affecting the exciton recombination process in the recombination zone near α–NPD/ Alq_3 interface.

Fig. 2 shows the current density-voltage and luminance-voltage characteristics of the V_2O_5 doped HTL device compared to the reference device. Compared with the reference device, the V_2O_5 doped HTL device exhibits lower operating voltage with higher current density and luminance. At a luminance of 1000 cd/m^2, V_2O_5 doped α-NPD device shows a operation voltage of 5.1V, while the device without V_2O_5 shows 5.8V. This is outstanding in lower voltage region where the injection of charge is the dominant restriction for operation.

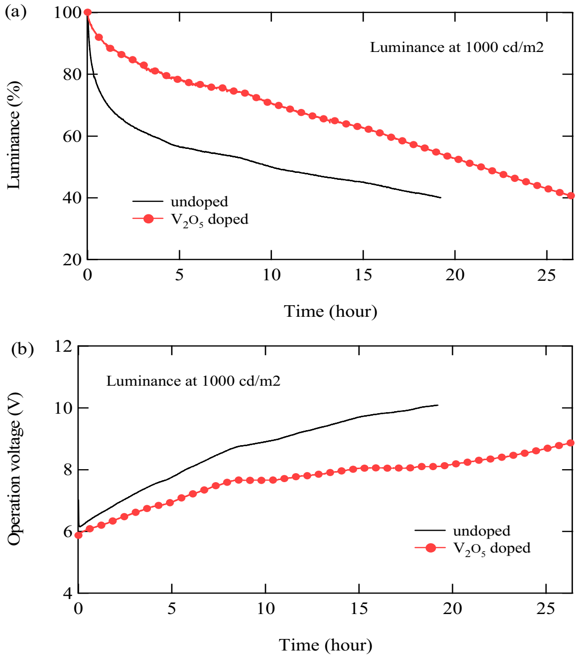

Figure 3. The device operational stability driven at room temperature; the luminance (a) and the operation voltage variation (b)

Since the total thickness is same and the only difference is the V_2O_5, the enhanced current density indicates that V_2O_5 effectively increases the hole injection efficiency.

Fig. 3 shows the operational stability of the two devices. The measurement is carried out at room temperature by applying a constant current for the initial luminance of 1000 cd/m^2 to each device. The slower luminance decay rate for the V_2O_5 doped α-NPD device indicate much longer operation lifetime.

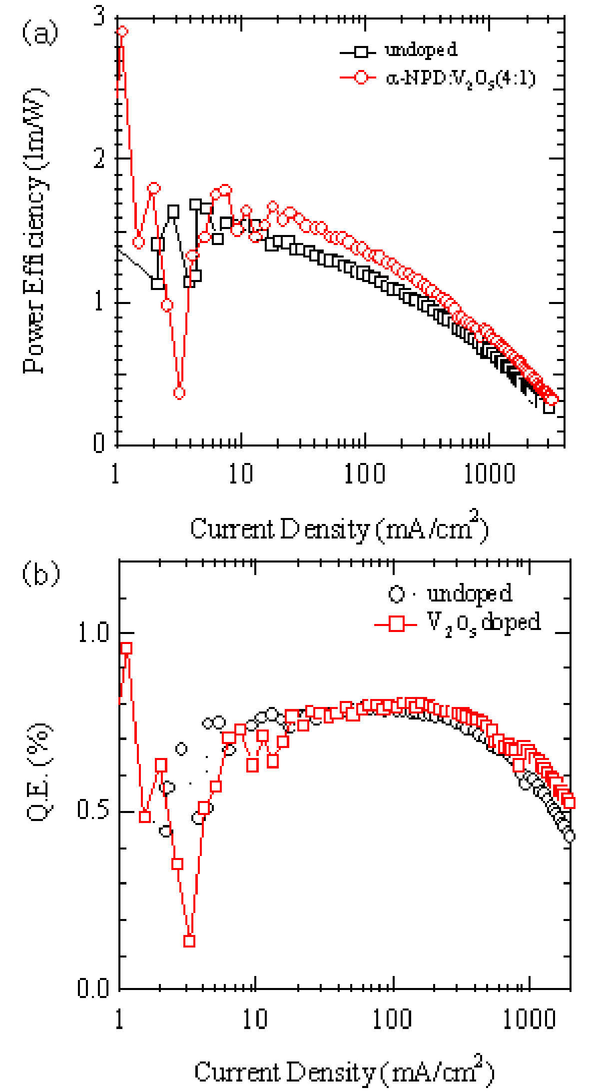

Figure 4. The power efficiency-current density (a) and Q.E- current density (b) characteristics

Fig. 4 shows the power efficiency-current density and external quantum efficiency (Q.E) - current density characteristics of the two devices. Compared with the reference device, the V_2O_5 doped HTL device exhibited somewhat higher power efficiency. For the device with the V_2O_5 doped HTL, the higher hole injection efficiency leads to slight unbalance of charges and thus resulting in the slightly lower QE. However, the insertion of the V_2O_5 doped HTL reduced the operational voltage significantly and thereby resulting in the much enhanced the luminous power efficiency.

3. Conclusion

We demonstrate that the low voltage operation and longer lifetime can be obtained by doping V_2O_5 into hole transport layer. It is attributed to the enhance hole injection at the anode by V_2O_5. This work will be a contribution for lowering the operation power and enhancing the stability of OLEDs which are most weak point of OLEDs for practical applications.

4. Acknowledgements

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