High-Efficiency Inverted Transparent Blue Organic Light-Emitting Devices

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Abstract

We report efficient inverted transparent blue OLEDs (ITOED) with an hole injection layer prepared by co-evaporation of WO_3 with NPB, which achieved a total current efficiency of 10.7 cd/A at 20 mA/cm^2 with light emits from both ITO bottom cathode and Au top anode in about 3:1 ratio.

1. Introducion

Typical OLEDs have a transparent electrode indium tin oxide (ITO) of high work function deposited on glass for anode and a reflective metal for cathode such as Mg: Ag[1] and Al/LiF[2] from which light is reflected and emits through the bottom ITO glass. Transparent or surface-emitting OLEDs have been considered as desirable structure since they can easily be integrated with thin film transistors in active-matrix display. In pervious studies, transparent OLEDs (TOLED) were fabricated by sputtering ITO as cathode[3,4], but the intense radiation energy created by sputtering could damage the organic layer and induce non-radiative relaxation of the injected carriers[5,6]. Nonetheless, it has been reported[7,8] that the maximum efficiency of inverted transparent OLED (ITOLED) using Au as semi-transparent anode with Coumarin-6 doped Alq_3 as emitting layer could reach 6.0 cd/A.[8]

In this paper, we have fabricated the highly efficient blue ITOLED from which light emitted from bottom ITO and top Au are about 3:1 with a total external current efficiency of 10.7 cd/A at a current density of 20 mA/cm^2. Besides, the threshold voltage was only 3.2 V and it only needed 6.3 V to drive the device to reach current density of 20 mA/cm^2. The structure of ITOLED had an ITO bottom cathode and a semi-transparent Au as top anode to allow light to emit through both device surfaces. It also had an hole injection layer made by co-evaporating WO_3 with NPB to enhance not only the hole injection but to also block the diffusion of Au.

2. Experiment and Results

In this work, the thickness and sheet resistance of indium tin oxide ITO glass used were 100 nm and 35 Ω/□, respectively. Prior to deposition, the ITO coated glass substrates were sequentially cleaned in acetone, isopropyl alcohol and deionized water and these materials were then deposited by thermal evaporation in an ULVAC SOLCIET OLED coater at a base vacuum of 10^{-7} torr. The active area of the EL device, defined by the overlap of the ITO and the cathode electrodes, was 3×3 mm^2. The current density−voltage−luminance (J−V−L) characteristics of the devices were measured with a Photo Research PR650 spectrophotometer and a computer-controlled programmable dc source (Keithley 2400).

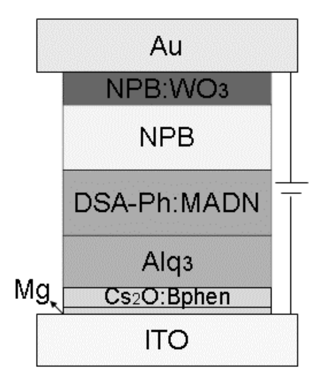

Figure 1. The structure of ITOLED.

The structures of our standard sky blue ITOLED was ITO / Mg[9] (3 nm) / Cs_2O: BPhen (11 nm, 20%)[10,11] /Alq_3 (15 nm) / DSA-Ph: MADN(40 nm, 3%) / NPB (55 nm) / WO_3: NPB (5 nm: 5 nm)/ Au (10 nm), as shown in Figure 1. The current density-voltage-luminance (*J-V-L*) characteristics of the blue fluorescent ITOLED device are shown in Figure 2. The turn-on voltage of the ITOLED is approximately 3.2 V. Furthermore, to reach the current density of 20 mA/cm^2, it only needs 6.3 V to achieve brightness of 1600 cd/m^2 and 540 cd/m^2 from ITO and Au, respectively.

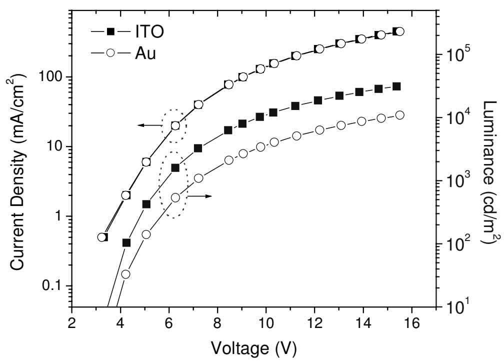

Figure 2. Current density-voltage-luminance characteristics of the blue fluorescent ITOLED device

From Figure 3, at a current density of 20 mA/cm^2, light emits with an efficiency of 2.7 cd/A from the semitransparent Au top anode and 8.0 cd/A from ITO/glass bottom substrate with a total external current efficiency of about 10.7 cd/A. The detailed performance of the ITOLED is shown in Table 1.

We attribute the high efficiency of our ITOLED device mostly to better electron/hole balance rather than the effect of microcavity. This is because we find that the yield is almost constant and independent of the various current densities. In particular, the EL intensity of the spectra as well as its FWHM remains unchanged under the different view angle, as shown in Figure 4. Generally, microcavity effect in TOLEDs is resulted from highly reflective metal and a semi-transparent cathode. But, we used highly transparent ITO for cathode and very thin Au for anode to reduce its intrinsic reflectivity in our ITOLED to alleviate such an effect. Thus, both sides of the ITOLED are of high transparency to allow light to escape.

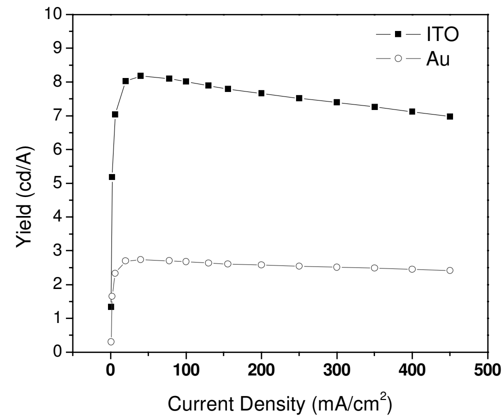

Figure 3. Current density-yield characteristics of the ITOLED

Table 1. Characteristics Performances of the inverted transparent OLED (ITOLED) at a current density of 20 mA/cm^2.

Light from	Lum. (cd/m^2)	Lum. Yield (cd/A)	C.I.E (x,y)	External Quantum Efficiency
ITO	1600	8.0	(0.205, 0.356)	3.50
Au	540	2.7	(0.170, 0.355)	1.22

We also found that Au is prone to short the devices when either NPB or WO_3 alone was used as HIL. We believe the short could be induced by the diffusion of Au into the organic layer. But, in order to match the HOMO of NPB with the work function of anode to get low operating voltage, it was necessary to choose a high work function metal like Au. It was discovered, however, that when NPB was co-evaporated with WO_3 as a composite hole-injection layer before the deposition of Au, all shorting problems could be effectively eliminated. In addition, by using this composite HIL, the efficiency of hole injection can be enhanced and the operating voltage is lowered as well[12,13]

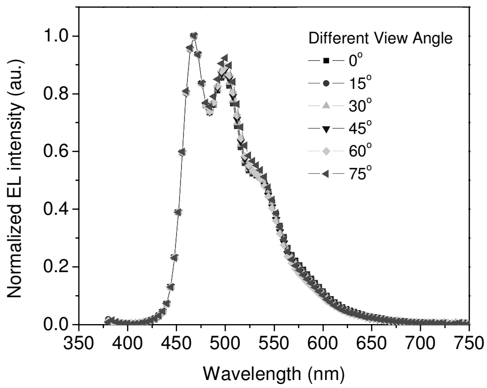

Figure 4. Wavelength-normalized EL intensity characteristics of the blue ITOLED under different view angle

3. Summary

We have demonstrated a highly efficient sky-blue ITOLED with a composite layer of WO_3 and NPB as HIL. It was found that the co-evaporation of WO_3 and NPB could alleviate the diffusion problem of Au that would otherwise cause device to short. The device achieved a total current efficiency of about 10.7 cd/A at 20 mA/cm^2 and the ratio of light emits from bottom ITO cathode and top Au anode was about 3:1. Furthermore, by using this composite HIL, the efficiency of hole injection can be enhanced and the operating voltage is lowered as well. As a result, the turn-on voltage of this ITOLED was about 3.2 V, and to reach 20 mA/cm^2, it only needed 6.3 V to achieve brightness of 1600 cd/m^2 and 540 cd/m^2 of light emissions from ITO and Au, respectively.

4. Acknowledgements

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5. References

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