P-55: Bright and Efficient Stacked White Organic Light-emitting Diodes

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Abstract

High brightness and efficient stacked white organic light-emitting diodes (WOLEDs) have been fabricated based on blue phosphorescent and red fluorescent emissive units consisting of NPB/mCP: FirPic/TPBi and NPB/Alq_3: DCJTB/BCP, respectively. White light emission with CIE coordinates of (0.32, 0.38) was obtained. A luminance of 40,000cd/m^2 was obtained using a driving voltage of 26V. The maximum luminous efficiency was about 11.6 cd/A at a current density of 28mA/cm^2.

1. Introduction

Stacked organic light-emitting diode (SOLED) has been widely investigated due to its potential application in making full-color OLED display as well as the next-generation light source [1-3]. In recent years, many research groups have developed stacked devices showing very high luminous efficiency [4-6]. SOLED can be a good candidate as a light source because doubled or even tripled current efficiency can be obtained as compared to conventional single emitter device. It is anticipated that stacked white light-emitting diode (WOLED) can produce higher brightness and efficiency than those of conventional WOLED. Such WOLED can function as light source for both general illumination and for LCD backlights. Currently, only a few reports on stacked WOLED (SWOLED) have been reported [7, 8].

Recently, we have successfully developed a novel anode-cathode layer (ACL) for connecting two adjacent emissive units to fabricate the highly efficient stacked OLED [9]. In the present report, we shall introduce a white stacked organic light-emitting diode using this ACL to connect one blue phosphorescent and a red fluorescent emissive unit. They consist of NPB/mCP: FirPic/TPBi and NPB/Alq_3: DCJTB/BCP, respectively. Efficient white light with a CIE coordinates of (0.32, 0.38) was obtained. A luminance of 40,000cd/m^2 was obtained under a driving voltage of 26V. The luminous efficiency is peaked at 11.6 cd/A at a driving current density of 28mA/cm^2.

2. Experimental details

Glass coated with 75nm indium-tin oxide (ITO) was used as substrates for the stacked organic light-emitting diodes. The sequence of pre-cleaning prior to loading into the surface treatment chamber consisted of soaking in ultra-sonic detergent for 30mins, spraying with de-ionized (DI) water for 10mins, soaking in ultra-sonic DI water for 30mins and oven bake-dry for 1hr. The organic materials were commercial grades and used as received. All the thin films were prepared by thermal evaporation in a four-chamber deposition system with the pressure lower than 10^{-6} Torr. The schematic architecture of the stacked white light-emitting diode along with the chemical structures of the organic materials used here is shown in Fig. 1. The structure of the SWOLED in this work is ITO/NPB (40nm)/mCP: FirPic (30nm, 10%wt)/TPBi (30nm)/**ACL**/NPB (50nm)/Alq_3: DCJTB (30nm, 1.5%wt)/BCP (20nm)/**ACL**/Reflective metal (80nm). Doping was achieved by co-evaporation from two separated sources. The typical deposition rates of organic thin films were 0.1-0.15nm/s, which was monitored by quartz oscillators *in situ*. The active area is defined by a shadow mask and is ~18mm^2.

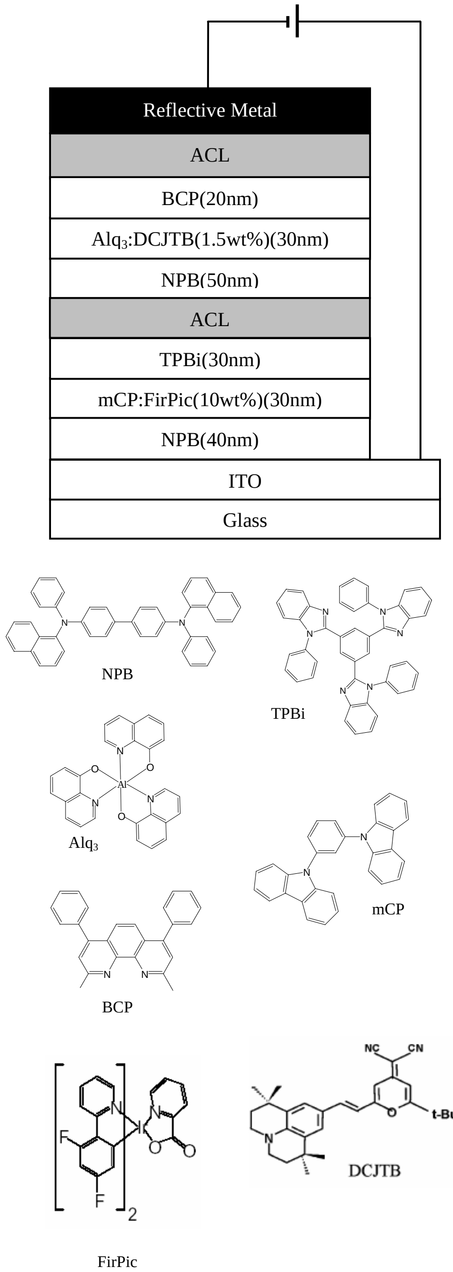

Figure1. Structure of stacked WOLED along with the molecular structures of organic materials used in this work.

The luminance-current density - voltage (L-J-V) characteristics of the devices were recorded simultaneously with a semiconductor parameter analyzer (HP4145B) combined with a calibrated silicon photodiode mounting above the device. The electroluminescent (EL) spectra were obtained from the PhotoResearch PR650 spectrometer. All measurements were carried out under ambient atmosphere without device encapsulation.

3. Results and discussion

Using the shadow mask, we patterned the ACL as a middle electrode so that we can measure the EL characteristics of two individual emissive units and total two-unit stack of the same device. Fig. 2 shows the normalized EL spectra of the bottom blue unit and top red unit under different driving voltages. As can be seen, the EL spectra of the individual emissive unit are almost unchanged with the increase of driving voltages. It is obvious that if the two emissive units are biased in a proper ratio, white light emission can be achieved.

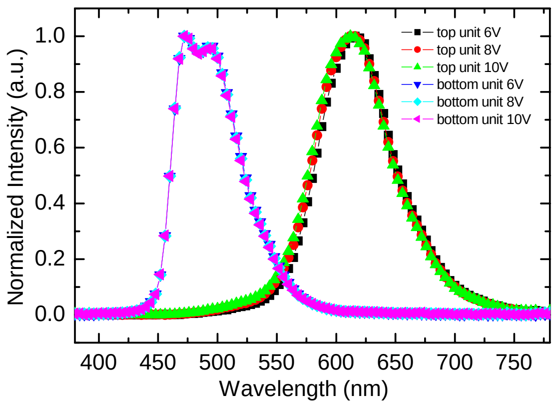

Figure2. The normalized EL spectra of bottom blue unit and top red unit under different driving voltage.

Fig. 3 shows an example spectrum of individually biasing two emissive units. The voltage for bottom blue unit and top red unit is 6V and 8V, respectively. However, this driving scheme is only suitable for achieving full-color display instead of lighting source due to higher power consumption needed for two individual single unit devices.

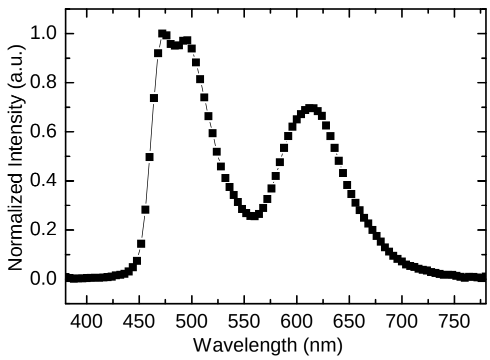

Figure3. EL spectrum when individually biasing the bottom and top unit of 6Vand 8V, respectively.

As reported before, the ACL can effectively act as the cathode of bottom unit and anode of top one [9]. Thus it is possible to simply apply a voltage across the two ends of the SWOLED to obtain emission from the two units. Electrons and holes are injected from the external cathode and anode. At the same time, holes and electrons are generated from the ACL and injected into the red top unit and blue bottom unit respectively. The holes and electrons recombine in the corresponding units to give light emission simultaneously. The red light and blue light emission from the top and bottom emissive units combine together to form white light.

Fig. 4 shows the EL spectra of the stacked white OLED under different driving voltages. The two peaks at ~472nm and ~612nm are undoubtedly generating from the FirPic and DCJTB, respectively. With an increase of the driving voltage, the red emission from the top unit is increases with respect to that of blue unit which also leading to a peak red shift from 472nm to 496nm of the FirPic. This is tentatively ascribed to a nonlinear voltage drop on the two emissive units due to different materials used together with impact of the ACL on the electrical field distribution, which is believed to influence the ratio of excitons formed in each emissive unit. Detailed simulation of the current and voltage distribution will be discussed elsewhere.

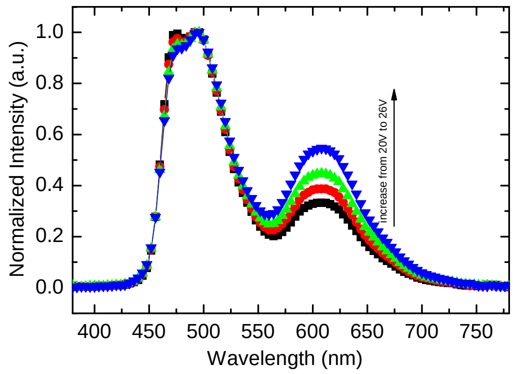

Figure4. The EL spectra of the stacked WOLED under different driving voltage.

From Fig. 4, it can be seen that with an increase of emission from the DCJTB, white light with better CIE coordinates is obtained. For example, at the bias of 26V, white light with CIE coordinates of (0.32, 0.38) at 40,000cd/m^2 is achieved. Brighter light with even better color purity close to pure white (0.33, 0.33) can be expected at higher voltages. However, breakdown of the stacked device is a problem.

Fig. 5 shows the overall EL characteristics of the SWOLED: (a) current density and luminance versus voltage; (b) luminous efficiency and external quantum efficiency versus voltage. The driving voltage is relatively high due to the large stack structure. The luminous efficiency is peaked at 11.6cd/A at the current density of 28mA/cm^2. The external quantum efficiency is relatively low due to the use of red fluorescent dopant DCJTB. We believe that the efficiency can be improved further if other phosphorescent red materials are used, such as $Btp_2Ir(acac)$.

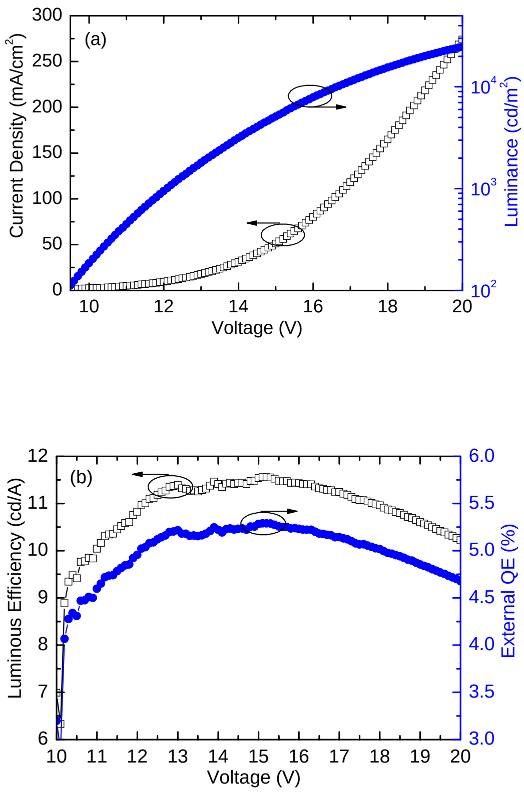

Figure5. (a) Luminance and current density versus voltage, (b) luminous efficiency and external quantum efficiency versus voltage curves of the stacked WOLED

4. Conclusion

A novel stacked white organic light-emitting diode using ACL to connect the blue and red emissive units has been demonstrated. Very high brightness (40,000-cd/m^2) white light with CIE coordinates of (0.32, 0.38) were achieved. More importantly, brighter and purer white light can be obtained at higher driving voltage. It is because that red emission increases more rapidly with respect to blue emission when the voltage is increased. These characteristics are very attractive for future lighting applications.

5. Acknowledgement

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6. References

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