P-129: Highly Efficient Stacked OLED Employing New Anode-Cathode Layer

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Abstract

Highly efficient stacked OLEDs have been fabricated using a new anode-cathode-layer (ACL) that connects two identical emissive units. The emissive unit consists of NPB/Alq_3: C545T/BCP or NPB/CBP: $Ir(ppy)_3$/BCP. The ACL can effectively function as both the cathode of bottom unit and the anode of top one. The luminous efficiencies are doubled with respect to the single unit device, and are peaked at 22cd/A (driving current density of 7.2mA/cm^2) and 60cd/A (1mA/cm^2) for C545T- and $Ir(ppy)_3$-based emission, respectively.

1. Introduction

Since Tang & van Slyke introduced the first ultra-thin and low-voltage organic light emitting diode (OLED) [1], much development has been made to improve this device for applications in flat panel displays as well as in solid state lighting [2]. Research on how to improve the device emission efficiency continues to be a major focus. In general, improved efficiency can be achieved through the use of highly efficient luminescent materials and in designing novel device structures. Kido et al, [3] fabricated a multiphoton device consisting of stacked units of OLEDs. The current efficiency can be multiplied because of electron and hole recycling.

The trick to a stacked device is to have a charge generation layer in between the stacks, which can be both an anode to one device and a cathode to the other device. Conductive material such as ITO or insulative material such as V_2O_5 or F_4-TCNQ has been used. Liao et al, [4] also introduced another kind of highly efficient tandem OLED, in which the connecting unit was made of organic materials consisting of a combination of Alq_3: Li/NPB: $FeCl_3$ or TPBi: Li/NPB: $FeCl_3$. Both of these devices showed very high luminous efficiency.

In the present work, we report a two-unit stacked OLED using a new ACL to connect the two devices. This ACL shows a good ability to inject electrons and holes to bottom unit and top one, respectively.

2. Structure and Fabrication

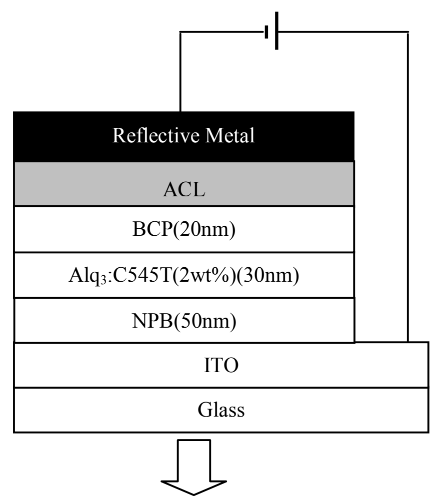
Figure 1 shows the structure of three devices that were fabricated.

Device A: ITO/NPB/Alq_3: C545T/BCP/**ACL**/Reflective Metal
Device B: ITO/**ACL**/NPB/Alq_3: C545T/BCP/**ACL**/Reflective Metal
Device C: ITO/NPB/Alq_3: C545T/BCP/**ACL**/ NPB/Alq_3: C545T/BCP /**ACL**/Reflective Metal

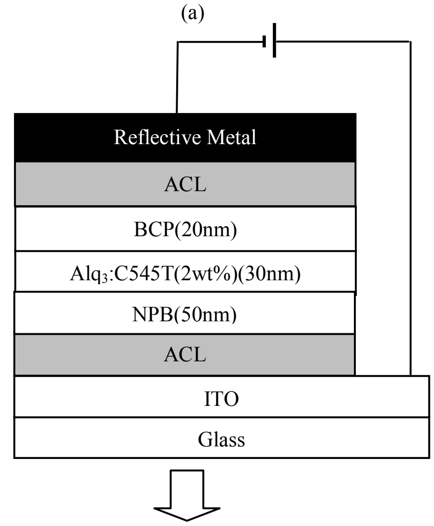
Devices A and B are single OLED structures aiming at examining the properties of the ACL. Device C is the double-stacked structure. They were all made on glass substrates coated with 75nm indium-tin oxide (ITO). The sequence of pre-cleaning prior to loading into the surface treatment chamber consisted 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 [5].

The organic materials were commercial grade and used as received. All thin films were prepared by thermal evaporation in a four-chamber deposition system. The whole fabrication process was carried out in vacuum without breaking the vacuum. The base pressure was lower than 10^{-4} Pa. The doping layer was achieved by co-evaporation from two separated sources. The typical deposition rates of organic thin films were 0.1-0.2nm/s. Quartz oscillators monitored film thickness *in situ*.

The luminance-current density-voltage (L-J-V) characteristics of the OLEDs were recorded simultaneously with HP semiconductor parameter analyzer (model HP-4145B) combined with a calibrated silicon photodiode. Measurement was carried out under ambient condition in room temperature without device encapsulation.



(a)



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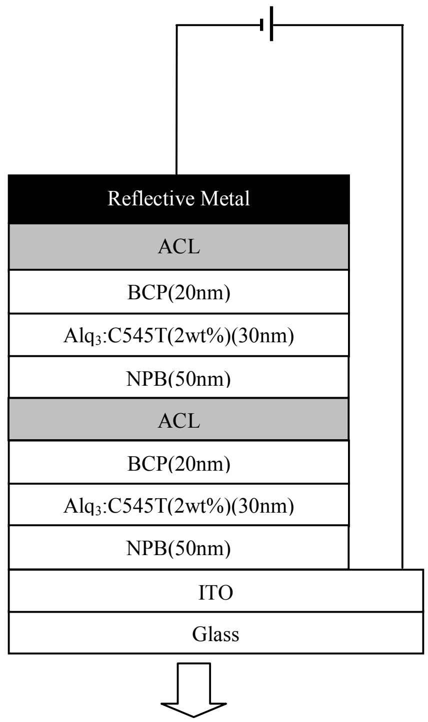

(c)

FIG. 1. (a) Structure of Device A, (b) structure of Device B,(c) structure of Device C. (Green emission from C545T**)**

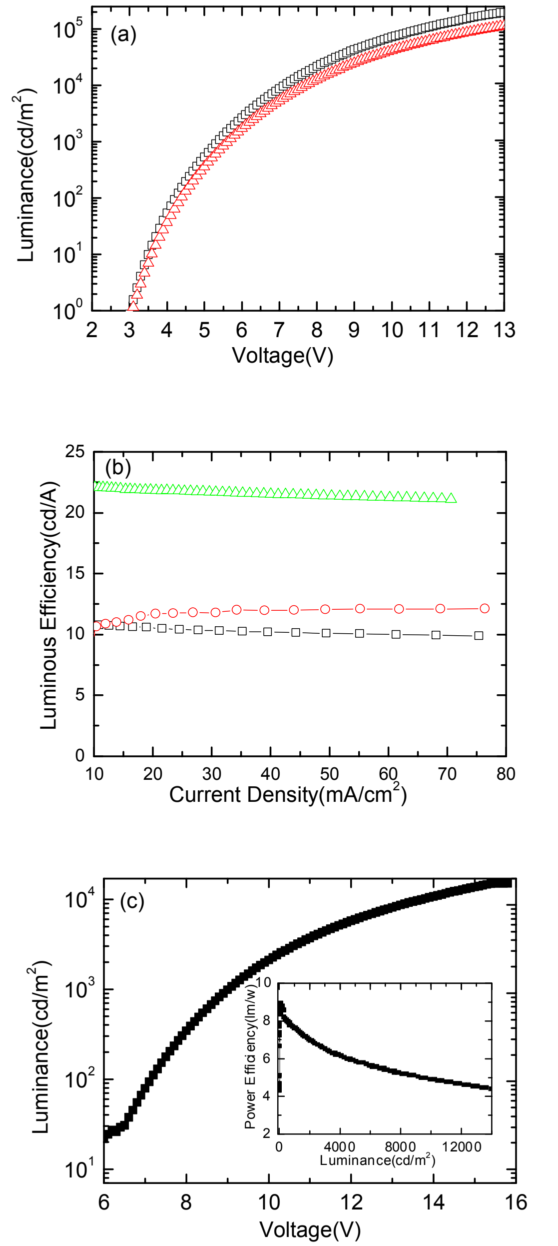

FIG. 2. (a) Luminance versus voltage of Device A (△) and B (□), (b) comparison of luminous efficiency versus current density between Device A (□), B (○) and C (△), (c) luminance versus voltage of Device C, inset: power efficiency vs luminance.

3. Results

Figure 2 shows the EL characteristics of the three devices: (a) Luminance versus voltage of Devices A and B. (b) Luminous efficiency versus current density for Devices A, B and C, (c) Luminance versus voltage of Device C. The inset is the power efficiency vs luminance for the same device. Device A and B both turn on at 3.0V (1cd/m^2) and reach a high luminance of more than 100,000cd/m^2 under the bias of less than 13V. It is obvious that the ACL can effectively inject electrons and holes in these devices. At 20mA/cm^2, the luminous efficiency of Device A is 10.5cd/A and that of Device B is 11.7cd/A, while it is 21.8cd/A for Device C. The efficiency of Device C is relatively constant with increasing current density and almost equals the sum of that of Device A and B. However, the luminance is much lower than that of the other two under the same driving voltage due to the stacked structure. The peak power efficiency is 8.92 lm/W with a luminance of 130 cd/m^2 and remains not lower than 5 lm/W even though the luminance is reaching 10,000cd/m^2.

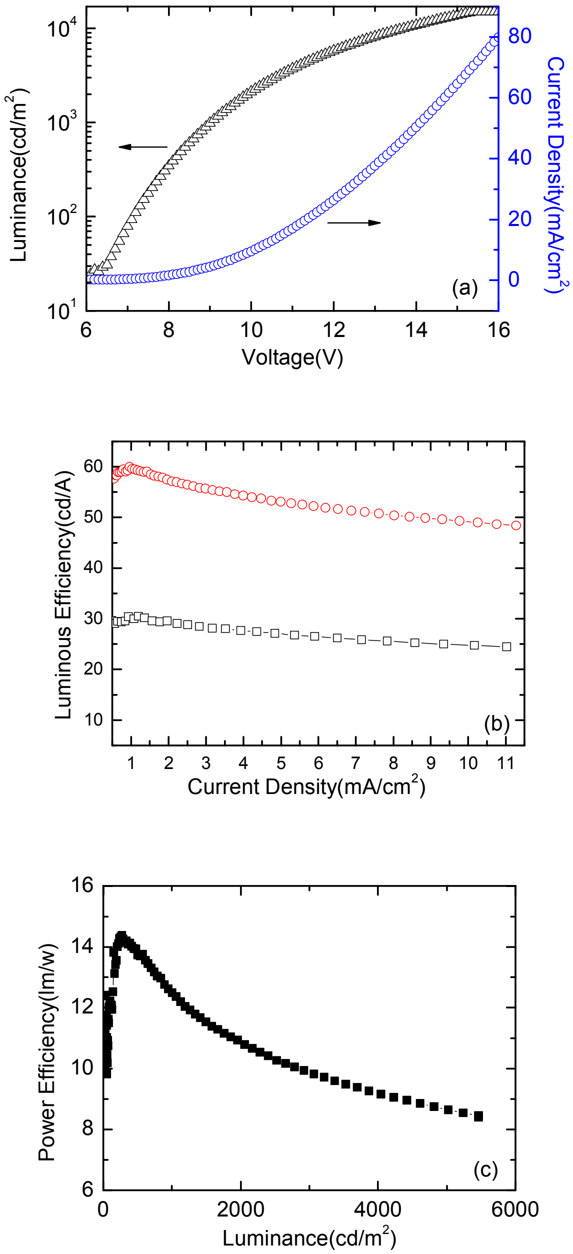

FIG. 3. (a) Luminance and current density versus voltage, (b) comparison of luminous efficiency versus current density between two-unit stacked device (○) and conventional one (□), (c) power efficiency vs luminance. (Green emission from $Ir(ppy)_3$)

Figure 3 shows the EL characteristics of the two-unit stacked device based on the emissive unit of NPB/CBP: $Ir(ppy)_3$/BCP: (a) Current density and luminance vs voltage. (b) Luminous efficiency vs current density. The result for a conventional device with a single emissive unit is also drawn for comparison (c) Power efficiency vs luminance. The luminous efficiency is indeed doubled compared to the conventional one. The maximum efficiency is 60cd/A at a current density of 1mA/cm^2. The power efficiency of this device is peaked at 14.4lm/W with a luminance of 270cd/m^2.

These results are very attractive for practical applications. Using this ACL to connect the adjacent emissive unit, a three- or four-unit stacked OLED [6] can also be made which is expected to have even higher luminous efficiency. Of course, the thickness of each layer has to be optimized as well for such a large stack of OLED. Presumably this can be realized by careful simulations using an electrical and optical model which we are now developing. More results will be reported in the near future.

It is also expected that the individual devices inside the stack should have strong microcavity effect. This microcavity effect can be taken advantage of to improve the device efficiency further, or minimized in order to reduce the angular dependence of the output color.

4. Summary

In this work, we have demonstrated that a stacked OLED can be made using the new ACL to connect adjacent identical emissive units. The luminous efficiency is truly doubled or equals to the sum of that of two individual devices. More importantly, its lifetime is expected to be longer than conventional one because of the higher luminous efficiency and lower operating current.

5. Acknowledgements

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6. References

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