Improved EL efficiency and operational lifetime of top-emitting white OLED with a co-doping technology

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Keywords : OLED, top-emitting, white, doping technology

Abstract

We have developed a top-emitting white organic electroluminescent device (TWOLED) incorporating a low-reflectivity molybdenum (Mo) anode and doped transport layers as well as a dual-layer architecture of doped blue and yellow emitters with the same blue host. The EL efficiency and operational lifetime of TWOLED can be enhanced by a factor of 1.2 and 3.4 than that of standard TWOLED, respectively, with a co-doping technology in yellow emitter by doping another blue dopant. The enhancement in device performances can be attributed to improve the energy transfer efficiency from blue host to yellow dopant through a blue dopant as medium in yellow emitter.

1. Introduction

Top-emitting organic electroluminescent device (TOLED) coupled with a low-temperature poly-silicon (LTPS) thin film transistor (TFT) active matrix backplane has been recognized as one of the best combination to achieve high display image quality due to it allow more complicated drive circuit beneath each of pixels without affecting its aperture ratio.[1] One of the most comportable full-color OLED technologies is to use a white OLED (WOLED) coupled with color filter (CF) since it can circumvent the problematic shadow mask for red-green-blue (RGB) pixelation in mass production and achieves a high-resolution large-sized displays.[2] Consequently, a full-color display of white emission established on top-emitting device architecture appears to be more attractive in recent years.[3,4]

OLED producing white light is generally to combine with two or more emitting materials due to the emission spectrum of typical organic materials only spans one-third of visible region (400-700 nm) and the device architecture can construct from one or multi emitters. The WOLED based on one emitter architecture can simply fabricate by a blue host doped with a red dopant through uncompleted energy transfer to generate white light,[5] whose Commission Internationale d'Eclairage coordinates ($CIE_{x,y}$) are independent to driving voltage owing to there was only one recombination zone. However, the low EL efficiency and small-range doping concentration of red dopant are the drawbacks in mass production. Utilizing multi emitters architecture to generate white light can chose adequate host material and optimal doping concentrate for each emissive dopant to get highest EL efficiency and suitable white chromaticity,[6] but the variation of $CIE_{x,y}$ with driving voltage are more serious than that of one emitter architecture which was attributed the shifting of recombination zone due to there was formed heterojunction between two different host materials. This issue can be solved, in recently, by adding a non-emissive dopant,[7] which was used an electron transport ability doped in hole-transporting host and *vice versa*, in dual-layer emitters to adjust the carrier balance and spread the recombination zone.

In this letter, we will report an efficient top-emitting WOLED incorporating a dual-layer emitter of doped blue and yellow dopant with the same blue host as well as a co-doping technology in yellow emitter by doping another blue dopant as an assistant dopant (AD). This two technologies can observably to avoid the variation of $CIE_{x,y}$ with driving voltage and improve the energy transfer efficiency from blue host to yellow dopant, respectively.

2. Experimental

Top-emitting WOLED architecture in this study is depicted in Figure 1, which constructs from a glass substrate of 100 nm thick Mo as reflective anode, a 20 nm *p*-type MoO_3 doped with hole transport material

EHI-608 (purchased from e-Ray Optoelectronics Technology Co., Ltd) is used as hole injection and transport layer (*p*-HTL),[8] 10 nm 4,4'-bis[N-(1-naphthyl)-N-phenyl-amino]biphenyl (NPB) and 4,7-diphenyl-1,10-phenanthroline (Bphen) are used as electron and hole blocking layers, respectively, a 10 nm *n*-type Cs_2CO_3 doped with Bphen is used as electron injection and transport layer (*n*-ETL),[9] a thin 1.5 nm Al and 17.5 nm Ag are used as bi-layer semitransparent cathode, finally a 30 nm capping layer of NPB is capped on the top cathode. In standard top-emitting WOLED, a dual-layer emitter with the same blue host are used, consisting of the 6 nm yellow emitter by 1% TC-1776 doped TC-1556 and 20 nm blue emitter by 4% TC-1754 doped TC-1556 (purchased from Tetrahedron Technology Co., Ltd), in addition, the TWOLED with AD is adding another 4% blue dopant of TC-1754 in yellow emitter by co-doping technology. All the materials were deposited by thermal evaporation in an ULVAC Solciet OLED coater at a base vacuum of 10^{-7} Torr. All devices were hermetically sealed with a glass cap in the glove box. The device performance of luminance yield and EL spectra, $CIE_{x,y}$ were measured by a Minolta luminance meter LS-110 and a Photo Research PR-650 spectrophotometer driven by a programmable dc source, respectively. The solid-state photoluminescence was measured by a HITACHI F-4500 fluorescence spectrophotometer.

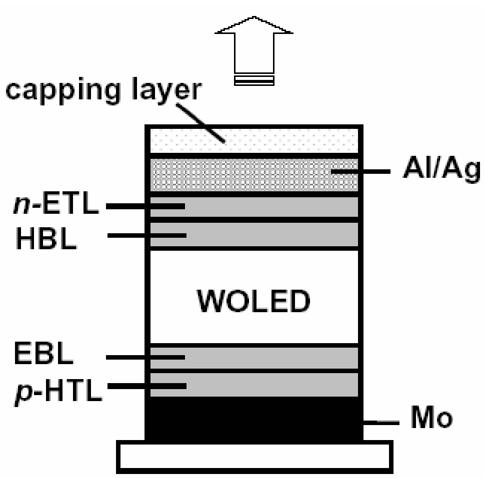

Fig. 1. The device architecture of top-emitting WOLED.

3. Results and discussion

The device performances of TWOLED are shown in Figure 2, where the standard TWOLED was attached an EL efficiency of 3.7 cd/A at 3,000 cd/m^2 and a low driving voltage of 4.9 V with a $CIE_{x,y}$ of (0.33, 0.39). The low driving voltage can be attributed to the *p*-HTL and *n*-ETL to alleviate the mismatch of energy barriers between electrodes and organic layers. The EL efficiency of TWOLED with AD in yellow emitter was attached an EL efficiency of 4.6 cd/A at 3,000 cd/m^2 and a driving voltage of 5.3 V with a $CIE_{x,y}$ of (0.33, 0.41). The enhancement in EL efficiency of TWOLED with AD in yellow emitter can be proven by the EL spectra, which are shown in Figure 3, it is clear to observe that the residual energy in the short wavelength (around ~430 nm) can be quenched and the EL intensity can be increased under the same current density in comparison with standard TWOLED. It can be suggested that, therefore, the enhanced EL efficiency was resulted from the improved energy transfer efficiency from blue host to yellow dopant through a blue dopant as medium in yellow emitter. Furthermore, the variation of $CIE_{x,y}$ of standard TWOLED and with AD in yellow emitter were nearly unchanged under a luminance from 1,000 to 5,000 cd/m^2, it can be attributed to use the same blue host in the dual-layer emitters to avoid forming heterojunction in-between.

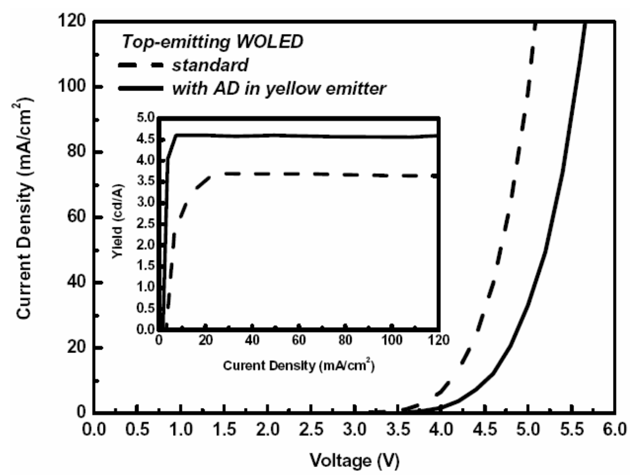

Fig. 2. *I-V* and *cd/A* characteristics of standard top-emitting WOLED and with assistant dopant (AD) in yellow emitter.

In order to investigate the energy transfer mechanism of TWOLED with AD in yellow emitter, the solid-state photoluminescence of pure blue host (100% TC-1556), yellow emitter (1% TC-1776@TC-1556) and yellow emitter with AD (1% TC-1776, 4%TC-1754@TC-1556) were measured, each of the samples was 20 nm thick and excited by 360 nm which was the less absorption for blue and yellow dopant. It is significantly to observe that the solid PL of yellow emitter exhibits two main peaks of 440 and 572 nm, which are shown in Figure 4, whose were originated from blue host and yellow dopant, respectively. This indicates that there was non-efficient Förster energy transfer from blue host to yellow dopant. When added a blue dopant as AD in yellow emitter, the blue host emission was not only entirely quenched as well as transferred the energy to blue dopant, but also the intensity of yellow emission as well as the total area under the emission were increased, confirming that the energy transfer efficiency from blue host to yellow emitter can be improved through a cascade process with a blue dopant as medium. The results can be replied to the increased EL efficiency of TWOLED with AD in yellow emitter.

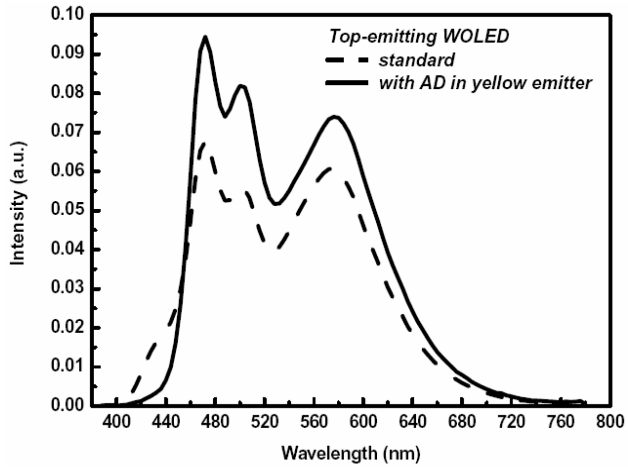

Fig. 3. The EL spectra of standard top-emitting WOLED and with assistant dopant (AD) in yellow emitter (under I= 100 mA/cm^2).

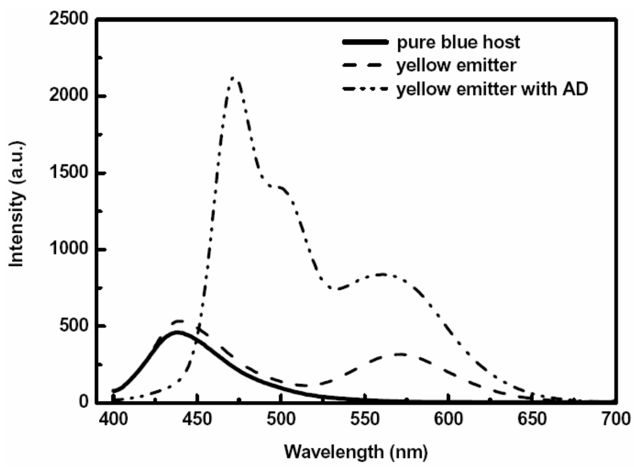

Fig. 4. The solid PL of pure blue host, yellow emitter and yellow emitter with AD.

The device operational lifetime of standard TWOLED and with AD in yellow emitter were measured with an initial luminance (L_0) of 1,000 cd/m^2 in ambient. After a continued operation for 850 hours, the luminance of TWOLED with AD in yellow emitter was reached 500 cd/m^2, which was 3.4 times longer than that of standard TWOLED of 250 hours. The enhancement in operational lifetime can be suggested that there was less Joule heating formation in the TWOLED with AD in yellow emitter due to it has a higher EL efficiency since it requires smaller current density driven at the same luminance than that of standard TWOLED. The others may be due to the entirely quenched energy of blue host in TWOLED whit AD in yellow emitter since the operational lifetime of doped blue device is generally longer than that of undoped blue device.[10,11,12]

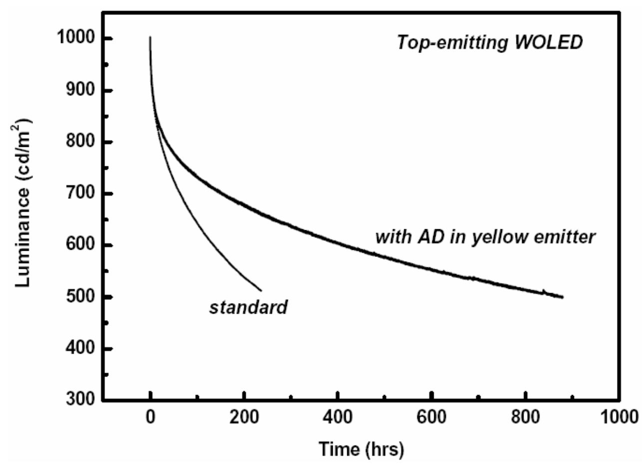

Fig.5. The operational lifetime test of standard TWOLED and with assistant dopant (AD) in yellow emitter.

4. Summary

The energy transfer efficiency between blue host and yellow dopant can be improved by a co-doping technology through a cascade process with a blue dopant as medium as well as the application for top-emitting white OLED, consisting of a dual-layer architecture of doped blue and yellow emitters, has been successfully demonstrated to improve the EL efficiency and operational lifetime with a stable CIE$_{x,y}$ under different driving voltage. We believed that the EL efficiency can be further improved by incorporating a high-reflectivity anode.

5. Acknowledgement

This work was supported by Bureau of Energy of Ministry of Economic Affairs under the grant number 6455-CJ-1211.

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