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White field-emission organic light-emitting diodes using a co-dopant emitter

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ABSTRACT: We report on blue phosphorescent organic light-emitting diodes (PHOLEDs) with a single emissive layer with co-dopant. The PHOLED consisting an emissive layer with 4,4'-bis(carbazol-9-yl)-biphenyl (CBP) as a host and 8 wt.% ridium(III)bis [(4,6-difluorophenyl)-pyri- dinato-*N*,$C^{2'}$] picolinate (Firpic) and 0.6 wt.% (2-methyl-6-[2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene] propane-dinitrile (DCM2) , has a luminous efficiency of 15 cd/A. The Commission Internationale de L'Eclairage(CIE) coordinates are x=0.36 and y=0.39, which is close to white point (0.33, 0.33). A field-emission organic light-emitting diode (FE-OLED) combining ITO/CNTs cathodes as electron source and an OLED is fabricated. The luminous efficiency is optimized and enhanced to 17.7 cd/A in the FE-OLED device.
Key words: organic light-emitting diodes, field-emission

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I. INTRODUCTION

Organic light-emitting diodes (OLEDs) have been widely recognized as a technology for flat panel display (FPD) products today and for potential future use in the lighting industry [1-2]. Several approaches for developing full-color organic displays have been proposed: patterned RGB subpixels, produced by precise shadow mask, conversion of blue emissions with fluorescent dyes method, and white emissions combined with color filters and stacked RGB cells. White light emission can be obtained by mixing light of two complementary colors (such as red/bluish green, blue/orange, or green/magenta) or the three primary colors (red, green, and blue) from small molecules and/or polymers. To obtain high luminance of a typical layered OLED, the light-emitting layer is generally doped with various fluorescent dyes or phosphorescent [3-6].

High-efficiency OLEDs employing phosphorescent materials, where the singlet and triplet excitons of the molecules contribute to light generation, have been demonstrated. Fluorescent emission involves emission from only singlet states of the organic molecule; its internal quantum efficiency has an upper limit of 25%. Blue phosphorescence involves both singlet and triplet excited states of metal-to-ligand charge transfer (MLCT), indicating a possible maximum internal efficiency of 100%. These PHOLEDs have been quickly developed owing to their high external quantum efficiency and power efficiency [7-8]. The phosphorescent materials were iridium (Ir) and platinum (Pt) complexes with organic ligands, and they were doped as an emissive guest into a charge-transport host material of the emissive layer. A number of strategies have been reported to make OLEDs emit white light [9-14]. These include multilayer OLED structure consisting of two or more active layers. Polymer POLEDs have single material in emissive layer and approach white.

In the work, we report a white OLED based on a single emissive layer with co-dopant of blue phosphorescent material and red fluorescence dye. Field-emission OLED (FE-OLED) uses an external electron source to increase the current injected into the OLED device, so that the recombination rate of electron-hole pairs inside the OLED is increased, and the OLED light emission is improved.

II. EXPERIMENT

The structure of OLEDs studied in this work used indium-tin oxide (ITO) on glass to be an anode and the stacked LiF/Al a cathode. ITO with a thickness of 150 nm and a sheet resistance of 15Ω/□ was cleaned by ultra-sonication in detergent, acetone and deionized water, respectively, before being treated with a UV-ozone ambient. After the substrate was loaded into an evaporation system, organic layers were sequentially fabricated at a rate of 1 ~ 2 Å/s onto substrates at room temperature by thermal evaporation from resistively heated tantalum boats, at a base pressure of 2 ~ 5 x 10^{-6} Torr. The organic

and mental is layers in separate evaporation chambers, and the thickness of the organic and the cathode layers are monitored independently in-situ by using quartz thickness monitors. The luminance-current density (L-J) and the current density-voltage (J-V) characteristics were measured using a Topcon SR-1 luminance meter at room temperature and an HP4156A precision semiconductor parameter analyzer. The electroluminescent (EL) spectra and the Commission Internationale De L'Eclairage (CIE) coordinates of these devices were also obtained using a Topcon SR-1. All of the measurements were taken using packaged devices at room temperature and atmospheric pressure.

III. RESULTS AND DISCUSSION

First, we optimized the doping concentration of FIrpic in blue phosphorescent devices. Fig. 1 plots the luminous efficiency and current density characteristics of PHOLEDs against the doping concentration of FIrpic in CBP. The luminous efficiency fell slowly as the current density increased for all devices, which finding is attributable to exciton quenching by triplet–triplet annihilation in electro-phosphorescent OLEDs. The maximum luminous efficiency of the blue PHOLEDs is 10.7, 16.9 and 13.7 cd/A at a current density of 4.17mA/cm^2, while FIrpic doping concentration is 6, 8 and 10 wt.%, respectively. When the FIrpic doping concentration is as high as 10 wt.%, friction arises among molecules in the CBP:FIrpic layer and corresponds to light emission from FIrpic. Emissive doping traps act as charges or absorb energy from the host, providing sites for electron-hole recombination and the formation of excitons. The concentration of phosphorescent dopant typically exceeds that of fluorescent dopants, which transfers energy through a short distance from the host to the guest in a phosphorescent dopant system. The dopant concentration must be increased to maximize the quantum efficiency of the phosphorescent device. The luminous efficiency of PHOLED reaches an optimal at a FIrpic doping concentration of 8 wt.%.

The Fig. 2 presents the typical EL spectrum of a PHOLED with FIrpic as the dopant. The spectrum includes two main peaks at 470 nm and 495 nm and the OLED has CIE coordinates of (0.17, 0.34). The Fig. 3 shows the photo-luminescence (PL) spectrum of FIrpic ahe absorption spectrum of DCM2 is also depicted in the inset of Fig. 3. We found the full width at half maximum (FWHM) of DCM2 is ~105 nm covering major part of the range from 420 to 525 nm. The FIrpic PL spectrum has a peak at 442 nm, it's nearly to 490 nm of DCM2's peak in absorption spectrum. It indicates the energy transits between FIrpic and DCM2.

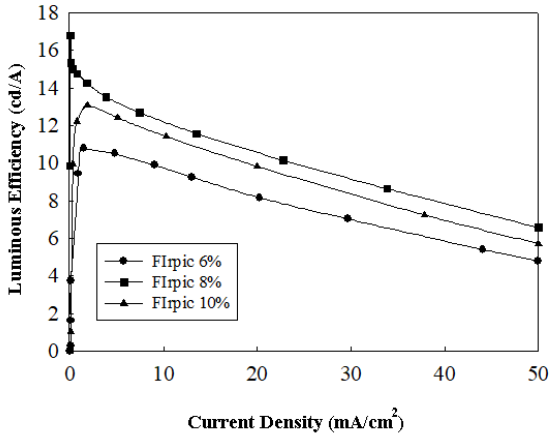

Figure 1: Luminous efficiency - current density characteristics of OLEDs against the doping concentration of FIrpic in CBP.

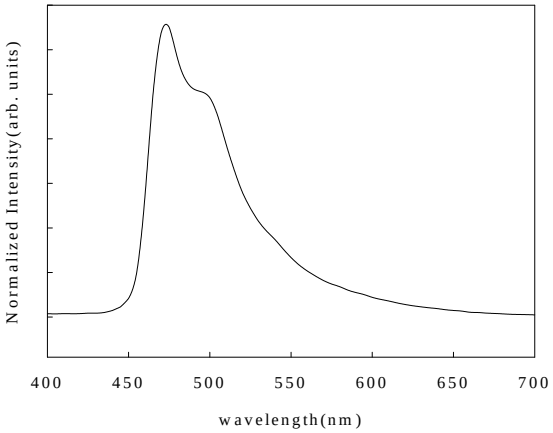

Figure 2: The electroluminance spectrum of PHOLED with FIrpic as the dopant.

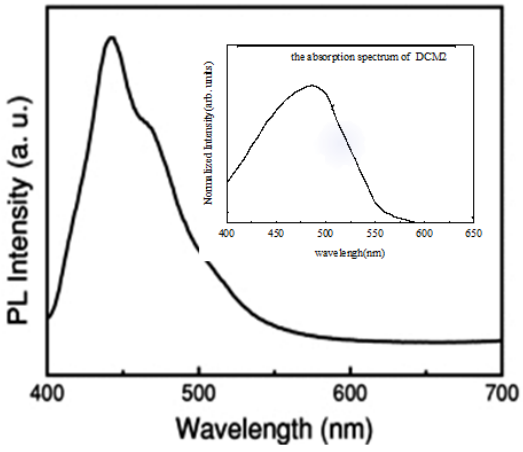

Figure 3: The photo-luminescence spectrum of FIrpic and the absorption spectrum of DCM2 in the inset.

Figure 4 shows the CIE coordinates of OLED with various DCM2 doping concentration. The doping concentration of DCM2 varies from 0.4 wt.% to 1 wt.%, while the doping concentration of FIrpic is fixed at 8 wt.%. The CIE of OLED with 0.6 wt.% DCM2 doping concentration is close to white point (0.33, 0.33). Fig. 5 shows the normalized EL spectrum of such an OLED device. Energy transfer between FIrpic and DCM2 exists and results in an obvious red light in EL spectrum. FIrpic is used as a sensitizer to invert the energy transfer between Dexter and Förster. The singlet excitons are transferred to the singlet states and the triplet excitons are transferred to the triplet states of FIrpic by a combination of Förster and Dexter processes along with carrier trapping.

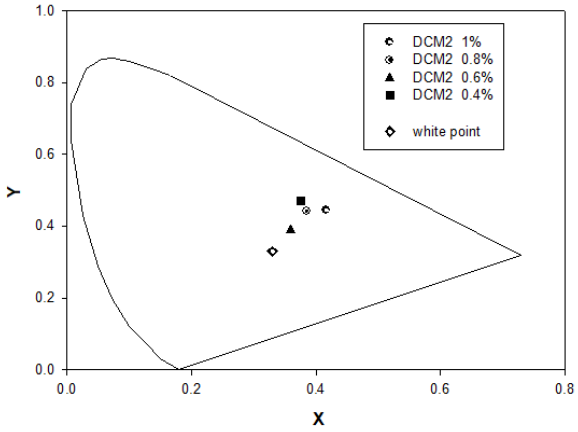

Figure 4: The CIE coordinates of OLED with various DCM2 doping concentration.

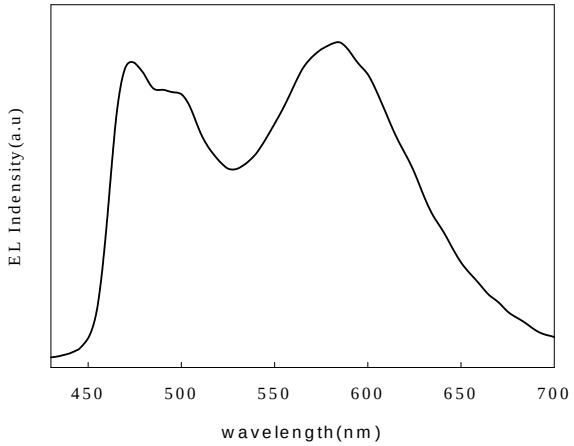

Figure 5: The normalized EL spectrum of white OLED device.

Figure 6 illustrates the schematic diagram of FE-OLED combining ITO/CNTs cathodes and an OLED device. Fig. 7 shows the luminous efficiency of both OLED and FE-OLED. The luminous efficiency of FE-OLED is 17.7 cd/A, which is higher than the luminous efficiency of OLED at the same current density. Adopting the ITO/CNTs cathodes will supply additional electrons and then cause the electrons and the holes to recombine more efficiently in the emitting layer.

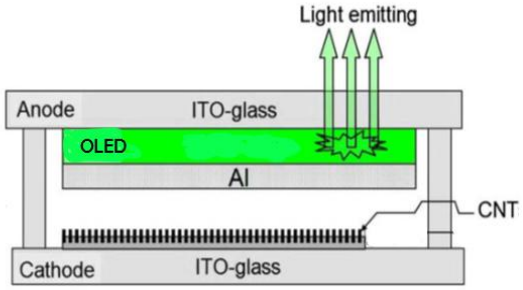

Figure 6: The schematic diagram of FE-OLED device.

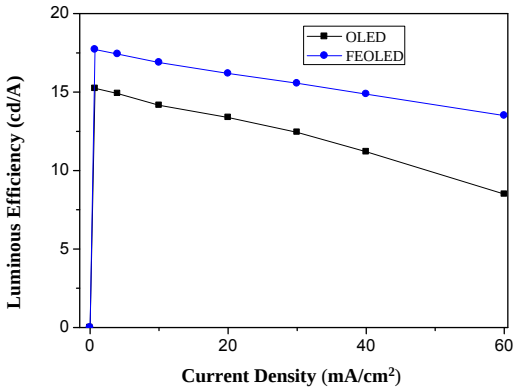

Figure 7: Luminous efficiency – current density of both OLED and FE-OLED devices.

IV. CONCLUSION

In this work, we have successfully fabricated a white OLED with co-dopant of FIrpic and DCM2. An OLED with co-dopant of FIrpic and DCM2 shows white EL spectrum owing to energy transfer of Förster and Dexter processes. The triplet–triplet annihilation yields self-quenching excitons at high current density, so the luminous efficiency decrease as the current density increases. A FE-OLED demonstrates the luminous efficiency of 17.7 cd/A, which is due to ITO/CNTs cathodes supply additional electrons and cause the electrons and the holes to recombine more efficiently in the emitting layer.

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