Color Tuning of OLEDs Using the Ir Complexes of White Emission by Adjusting the Band Gap of Host Materials

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Abstract

We report on white organic light-emitting diodes (WOLEDs) based on single white dopants, $Ir(pq)_2(F_2\text{-}ppy)$ and $Ir(F_2\text{-}ppy)_2(pq)$, where F_2-ppy and pq are 2-(2,4-difluorophenyl) pyridine and 2-phenylquinoline, respectively. The similar phosphorescent lifetime of two ligands lead to luminescence emission in two ligands simultaneously. However, the emission color of the devices was reddish, because the energy was not transferred efficiently from the 4,4,N,N'-dicarbazolebiphenyl (CBP) to the F_2-ppy ligand, due to the small band gap of the CBP. Accordingly, we used 1,4-phenylenesis(triphenylsilane) (UGH2) with a large band gap, instead of CBP as the host material. As a result, it was possible to adjust the emission color by the host material. The luminous efficiency of the device with $Ir(F_2\text{-}ppy)_2(pq)$ doped in UGH2 was about 11 cd/A at 0.06 cd/m^2.

Keywords : White organic light-emitting diodes, single white dopant

1. Introduction

White-light emission from organic compounds has been of increased interest, due to its potential impact on the lighting industry and backlight applications. Various strategies to fabricate WOLEDs include the manufacture of multilayer OLEDs by consecutive evaporation, and that of the single layer polymer blend devices, where all the emitting components are mixed in one layer[1-6].

In both devices, the emission color is sensitive to the device structure, such as layer thickness and doping concentration. This technique requires complex technological processes and a large amount of wasted organic materials, resulting in relatively high fabrication cost. Spin-coating of a blend of different soluble emitters in a single layer seems to be a cost-effective technique [7-8]. Though cheaper, this approach has a drawback. Customized color combinations are not always possible, due to Förster transfer from the high energy emitting material (donor) to the low-energy one (acceptor). This induces emission from the lower-gap com-

pound [9-10]. An alternative approach, which overcomes such a problem, is to blend two blue-light-emitting organic molecules of different electron affinities, whose interaction gives rise to exciplex states [11-12]. The combination of exciplex emission with blue-light emission of the individual donor molecule results in the generation of white light. In both of these approaches, the purity of the color emission is strongly dependent on the relative concentration of the different molecular species and, generally, on the applied voltage. This is a problem for lighting applications in which the source intensity (but not the color) has to be varied by changing the applied electrical power. Furthermore, the use of charge blockers to confine the charges and excitons causes high driving voltage and low efficiencies in multilayer white devices. Colors are dependent on the driving voltage in the single layer polymer devices. Most of problems seem avoidable if a single-component material can be used as the emitting species.

Although a few single emitting component WOLEDs have been reported in which white electroluminescence comes from the individual lumophore and excimer (or electromer), no single emitting component WOLED has yet been reported. In this paper, we demonstrate single dopant single emissive layer WOLEDs based on heteroleptic triscyclometalated iridium(III) complex, $Ir(pq)_2(F_2\text{-}ppy)$ and $Ir(F_2\text{-}ppy)_2(pq)$.

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2. Experiments

OLEDs were fabricated by high vacuum (5×10^{-7} Torr) thermal deposition of organic materials on the surface of an indium tin oxide (ITO, 30 $\Omega/\square$, 80 nm) coated glass substrate. The ITO glass was cleaned with acetone, methanol, distilled water and isopropyl alcohol[13]. The organic materials were deposited in the following sequence: 60 nm of 4,4′,4″-tris[2-naphthylphenylamino]triphenylamine (2-TNATA) and 20 nm of 4,4'-bis[N-(naphthyl)-N-phenyl-amino]biphenyl (NPB) were applied as a hole injection layer (HIL) and a hole transporting layer (HTL), respectively, followed by a 30 nm thick emissive layer (EML) of the Ir complexes doped in host material. The host material was 4,4,N,N'-dicarbazolebiphenyl (CBP) or 1,4-phenylenesis(triphenylsilane) (UGH2). The doping rate of the phosphors, $Ir(pq)_2(F_2\text{-}ppy)$ and $Ir(F_2\text{-}ppy)_2(pq)$, was 10 %. 10 nm thick bathocuproine (BCP), 20 nm thick tris-(8-hydroxyquinoline) aluminum (Alq_3) and 2 nm thick Lithium quinolate (Liq) were deposited as an exciton blocking layer, as an electron transporting layer (ETL) and as an electron injection layer (EIL), respectively. The typical organic deposition rate was 0.1 nm/sec. Finally, 100 nm of Al was deposited as a cathode. Configuration of device and molecular structure of materials used as host and dopant are shown in Fig. 1 and Fig. 2. The active area of the OLEDs was 0.09 cm^2. After fabrication, the current density–voltage (J-V) characteristics of the OLEDs were measured with a source measure unit (Kiethley 236). The luminance and CIE chromaticity coordinates of the fabricated devices were measured using a chromameter (MINOLTA CS-100A). All measurements were performed in ambient conditions under DC voltage bias.
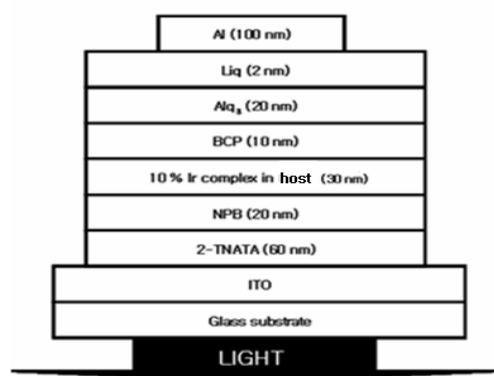

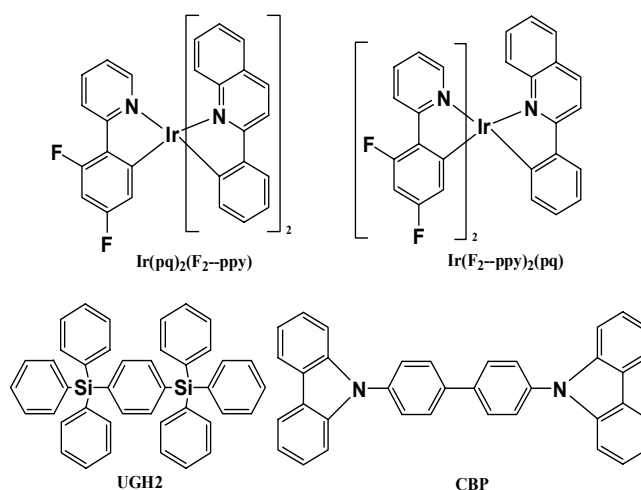**Fig. 1.** Configuration of devices used in this study.

Fig. 2. Molecular structure of materials used as host and dopant.

3. Results and discussion

New phosphorescent iridium complexes, having a different species of plural ligands, are designed for the application in WOLEDs, to emit white color and to improve luminescence efficiency by avoiding T-T annihilation. The devices prepared can be classified in two groups to confirm the host's influence in the emissive layer. The first group includes CBP as host, while the second one involves UGH2 as host. The iridium complexes, $Ir(pq)_2(F_2\text{-}ppy)$ and $Ir(F_2\text{-}ppy)_2(pq)$ were used as dopant in the host material, where the F_2-ppy and pq are 2-(2,4-difluorophenyl) pyridine and 2-phenylquinoline, respectively.

Fig. 3 and the figure inset in Fig. 3 show the luminous efficiency and power efficiency of the devices with CBP as an increase of the current density, respectively. The maximum luminous efficiency and power efficiency were 3.65 cd/A (@ 6.45 mA/cm^2) and 2.57 lm/W (@ 0.01 mA/cm^2) for device with $Ir(pq)_2(F_2\text{-}ppy)$, and 22.50 cd/A (@ 0.51 mA/cm^2) and 14.60 lm/W (@ 0.04 mA/cm^2) for device with $Ir(F_2\text{-}ppy)_2(pq)$, respectively. The devices with $Ir(pq)_2(F_2\text{-}ppy)$ and $Ir(F_2\text{-}ppy)_2(pq)$ had the luminance of 9100 cd/m^2 and 22900 cd/m^2, respectively at 14 V. Fig. 4 shows the electroluminescence (EL) spectra of devices with CBP at an applied voltage of 12V. Against expectation in both devices, the emission color of fabricated devices was reddish, because the energy was not transferred efficiently from the CBP to the F_2-ppy ligand, due to the small band gap of the CBP. Therefore, we used UGH2 of large band gap, instead of CBP as host material to obtain the strong blue intensity in EL spectra. The second group of fabricated
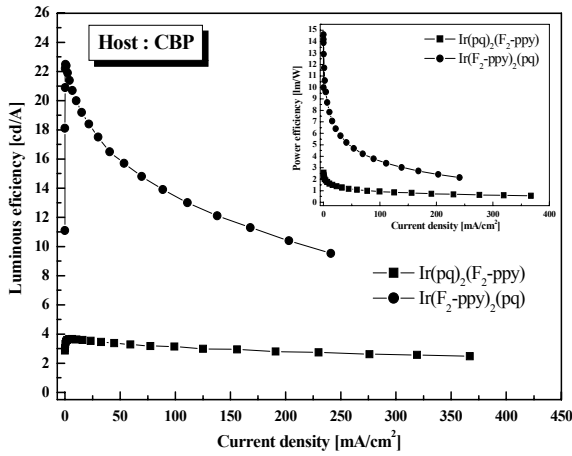
Fig. 3. Luminous efficiency (inset; power efficiency) curves, increasing current density of OLEDs with CBP host.
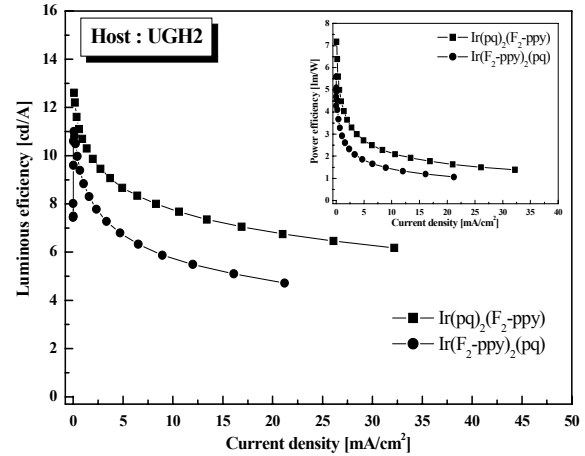

Fig. 5. Luminous efficiency (inset; power efficiency) curves. increasing current density of OLEDs with UGH2 host.
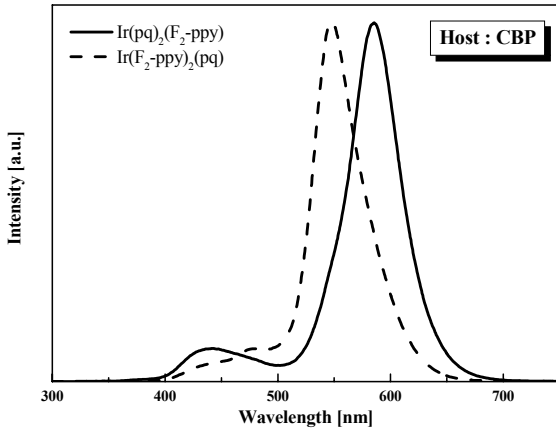

Fig. 4. Electroluminescence (EL) spectra of OLEDs using CBP host, applied voltage is 12 V.
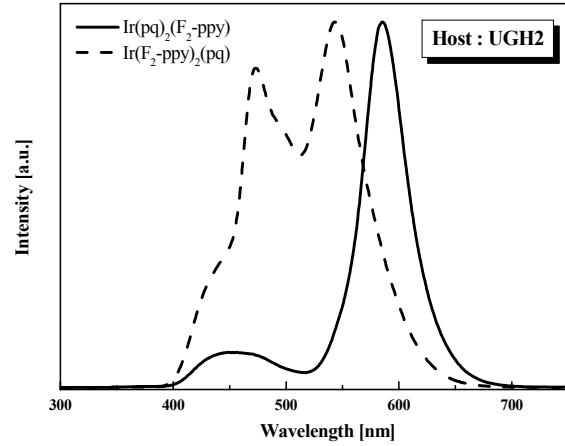

Fig. 6. Electroluminescence (EL) spectra of OLEDs using UGH2 host, applied voltage is 12 V.

devices electrical and optical characteristics are shown in Fig. 5 and Fig. 6, respectively. The maxima luminous efficiency and power efficiency of devices with UGH2 were 12.60 cd/A (@ 0.08 mA/cm^2) and 7.18 lm/W (@ 0.08 mA/cm^2) for device with Ir(pq)$_2$(F$_2$-ppy), and 11.00 cd/A (0.05 mA/cm^2) and 5.60 devices, the emission color of fabricated devices was reddish, because the energy was not transferred efficiently from the CBP to the F$_2$-ppy ligand, due to the small band gap of the CBP. Therefore, we used UGH2 of large band gap, instead of CBP as host material to obtain the strong blue intensity in EL spectra. The second group of fabricated devices electrical and optical characteristics are shown in Fig. 5 and Fig. 6, respectively. The maxima luminous efficiency and power efficiency of devices with UGH2 were 12.60 cd/A (@ 0.08 mA/cm^2) and

7.18 lm/W (@ 0.08 mA/cm^2) for device with Ir(pq)$_2$(F$_2$-ppy), and 11.00 cd/A (0.05 mA/cm^2) and 5.60 lm/W (0.0007 mA/cm^2) for device with Ir(F$_2$-ppy)$_2$(pq), respectively, as shown in Fig. 5. The luminance was 9100 cd/m^2 and 22900 cd/m^2 for Ir(pq)$_2$(F$_2$-ppy) and Ir(F$_2$-ppy)$_2$(pq), respectively, at 14V. We confirmed that the electrical characteristics of devices with UGH2 were worse than those with CBP, because UGH2 has a wide energy band gap of 4.4 eV [14]. That is, carriers injected from electrode were hardly transported to HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital) of UGH2 in the emissive layer, due to the high energy barrier. However, we obtained white emission from the device with Ir(F$_2$-ppy)$_2$(pq) and UGH2 as dopant and host, respectively (Fig. 6). For the device with

Ir(pq)$_2$(F$_2$-ppy) and UGH2, the EL characteristic was reddish, because two pq ligands have strong MLCT (Metal to Ligand Charge Transfer) characteristics. When Ir(F$_2$-ppy)$_2$(pq) was placed in an excited state, the absorbed energy may then be thought to emit each ligand without energy transfer, because of their similar phosphorescent lifetime and the stronger MLCT characteristics of the pq ligand than that of the F$_2$-ppy ligand. Emission wavelengths and the lifetime of Ir(F$_2$-ppy)(acac) and Ir(pq)$_2$(acac) were reported as 469 nm (1.6 μs) and 597 nm (2.0 μs), respectively [15-16]. The wide energy band gap of UGH2 helps the excitons formed in the host transfer to HOMO of F$_2$-ppy ligands. White color, combining the blue and orange emission emitted simultaneously, can be observed.

4. Conclusions

We report OLEDs with white emissive single dopant in a single emissive layer, based on the heteroleptic tris-cyclometalated iridium(III) complex, Ir(pq)$_2$(F$_2$-ppy) and Ir(F$_2$-ppy)$_2$(pq), as the guest. The blue peak due to F$_2$-ppy ligand of Ir(F$_2$-ppy)$_2$(pq) in EL spectra was stronger for the device with UGH2 than with CBP as host, because of the wide energy band gap of the F$_2$-ppy ligand. Therefore, white elecroluminescence was observed on the device with UGH2 and Ir(F$_2$-ppy)$_2$(pq) as host and dopant, respectively. The maximum luminous and power efficiencies of the device were 11.00 cd/A (J = 0.05 mA/cm^2) and 5.60 lm/W (J = 0.001 mA/cm^2), respectively. The dopant with blue emissive ligands depends on the host energy band gap.

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