

Low voltage driving red phosphorescent organic light-emitting devices

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Abstract

We have developed low voltage driving red phosphorescent organic light-emitting devices using a new electron transport layer. Ir(piq)₃ and CBP were used as a phosphorescent dopant and an emission host, respectively. The device exhibits a luminance of 1000 cd/m² at a voltage of 2.8 V. This high luminance at low voltage results from a high electron conduction behavior of the new electron transport layer.

1. Introduction

Organic light emitting devices (OLEDs) have been attracted in recent years because of their excellent electrical and optical properties in display and lighting applications. In particular, the phosphorescent OLEDs have been more and more interested because they can harvest single and triplet excited states, resulting in high quantum efficiency device. However, low voltage operation of organic light-emitting devices (OLEDs) has been a critical issue in realizing low power consumption display and high power efficiency lighting applications. Since the electron mobilities of typical electron transporting materials are lower than those of hole transporting materials, the approaches for low voltage devices have been focused on the electrical doping of electron or hole donating dopants such as Li, Cs, Cs₂CO₃, WO₃, and F₄TCNQ into the organic hole and/or electron transport and/or injection layers [1-3]. However, these electrical impurities may diffused inside the organic layers, being incorporated in the emission zone, leading to the decrease of lifetime of the device owing to the impurity induced quenching of excitons.

We have developed low voltage driving red phosphorescent OLEDs using a new electron transport layer. The device with a new electron transport layer exhibits a high current density at a low applied voltage, leading to a high luminance of 1000 cd/m² at a low driving voltage of 2.8 V.

2. Experimental

OLEDs were fabricated on indium tin oxide (ITO) coated glass substrates. The sheet resistance of ITO film was about 10 Ω/□. The ITO anode patterns were defined by using a standard photolithography process. After cleaning of patterned ITO substrates, organic and metal layers were deposited. All organic and metal layers were deposited by using a thermal evaporation method in a base pressure of about 1 × 10⁻⁶ torr. A 15 nm thick 4,4',4''-tris[N-(2-naphthyl)-N-phenyl-amino] triphenylamine (2-TNATA) layer was deposited on the patterned ITO substrate. 2-TNATA layer acts as a hole injection layer and electron blocking layer. In some devices, a 10 nm thick 4,4'-bis-[N-(1-naphthyl)-N-phenyl-amino] biphenyl (α-NPD) layer was used as an hole transport layer. 4,4'-N,N'-dicarbazole-biphenyl (CBP) and tris[1-phenylisoquinolino-C2,N]iridium(III) (Ir(piq)₃) were used as an emitting host and a red phosphorescent dopant, respectively. The Ir(piq)₃ concentration was varied from 0% to 20% for the investigation of electrical and optical properties of device. We didn't use the hole blocking layer such as 2,0-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP). After the deposition of the organic layers, a 0.5 nm thick LiF and 100 nm thick Al layers were sequentially evaporated through the shadow mask. The deposition rate of organic layers was maintained to be 0.1 nm/s. All the completed devices were encapsulated without exposing to air in a nitrogen atmosphere glove box. Current density-voltage-luminance (J-V-L) characteristics of the devices were measured using computer controlled Keithley 2400 source-measure units and a luminance meter. Electroluminescence (EL) and photoluminescence (PL) spectra were measured with a spectroradiometer.

3. Results and discussion

Electrical conduction properties of red phosphorescent OLED with a new electron transport layer were investigated. Ir(piq)₃ and CBP were used as a red phosphorescent dopant and an emission host, respectively. The dopant concentration was varied from 2 to 20 %. Figure 1 shows the current density as a function of applied voltage for the red phosphorescent device with a new electron transport layer. The devices show very high current densities at low applied voltages. The current density is comparable to that of p-i-n device [3]. The high current density is clearly attributed to the new electron transport layer because the current density is much lower when the other typical electron transport layer was used instead of new electron transport layer. The current density is higher at high concentration of Ir(piq)₃. The better electrical conduction in high Ir(piq)₃ concentration device may be attributed to the hopping conduction of carriers through the Ir(piq)₃ molecules. Since the highest occupied molecular orbital (HOMO) energy level of Ir(piq)₃ is located inside the band gap of CBP emission host, the holes can be hopped through the HOMO level.

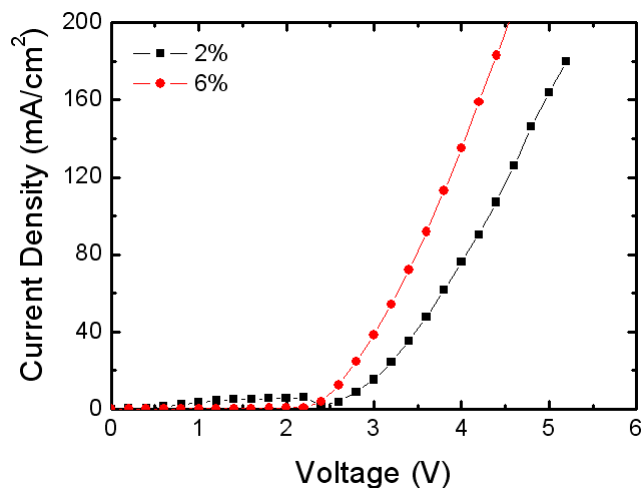


Fig. 1. Current density curves as a function of applied voltage for the red phosphorescent OLEDs with a new electron transport layer. Ir(piq)₃ concentration was varied from 2 to 20%.

Figure 2 shows the emitting devices at various applied voltages. The emission can be seen at just 2.2 V. In addition, the emission of device looks very deep red, indicating very good color coordinates. At an applied voltage of 2.3 V, the device becomes bright.

At an applied voltage of 3.0 V, the device becomes very bright. This result clearly indicates that the extremely low driving voltage of our red phosphorescent device is resulting from our new electron transport layer

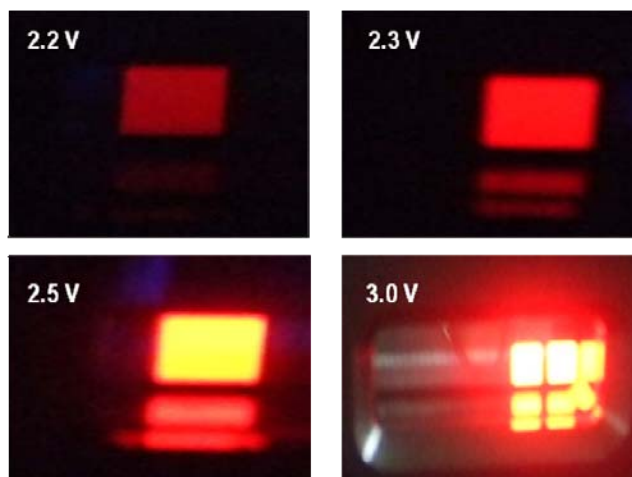


Fig. 2. Photographs of emitting red phosphorescent devices with new electron transport layer at various operating voltages. The emitting area is 4 mm x 4 mm.

Figure 3 shows the luminance curves as a function of applied voltage for the red phosphorescent OLEDs with new electron transport layer. The Ir(piq)₃ concentration was varied from 2 to 20 %.

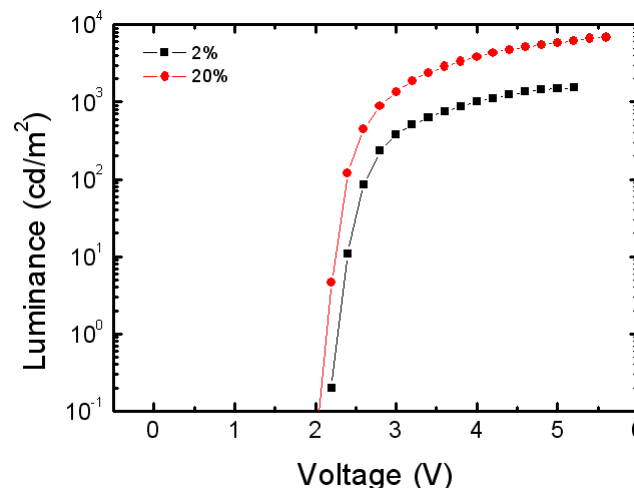


Fig. 3. Luminance curves as a function of applied voltage for the red phosphorescent OLEDs with a new electron transport layer. Ir(piq)₃ concentration was varied from 2 to 20%.

The devices show high luminances at very low voltages. For example, the device with 20% Ir(piq)₃ shows very low turn-on voltage (a voltage for achieving a luminance of 1 cd/m²) of 2.1 V. The device with 2% Ir(piq)₃ shows slightly higher turn-on voltage of 2.2 V. All other devices with different concentrations show low turn-on voltage. The luminance of device increases very rapidly with increasing driving voltage. For example, the device with 20% Ir(piq)₃ shows 120 cd/m² at a voltage of 2.4 V, being a luminance of 1000 cd/m² at an extremely low voltage of 2.8 V. The device with 2% shows higher driving voltage for achieving same luminance. For example, an applied voltage of 4.0 V is required to achieve a luminance of 1000 cd/m², although this driving voltage is still lower than other non-pin devices. This high luminance at a low voltage is clearly attributed to the high current density at low voltage by the high conductivity new electron transport layer.

Figure 4 shows electroluminescence spectra of the red phosphorescent devices with a new electron transport layer. Ir(piq)₃ concentration was varied from 2 to 20%.

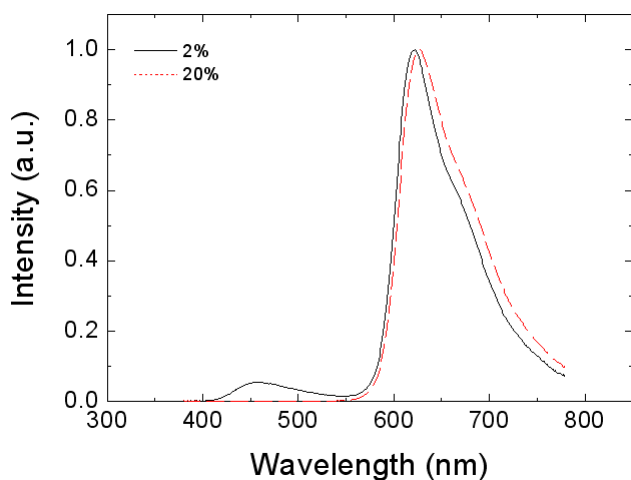


Fig. 3. EL spectra for the red phosphorescent devices with new electron transport layer. Ir(piq)₃ concentration was varied from 2 to 20%.

The device with 20% Ir(piq)₃ shows strong EL peak at 625 nm which peak originates from the emission of Ir(piq)₃. The device with 2% Ir(piq)₃ shows slight blue-shift of emission spectrum, resulting from solid state solvation effect. The device shows very deep red color coordinates. On the other hand, the device with

2% Ir(piq)₃ shows weak EL peak at about 450 nm. This peak may due to the CBP host or other hole transport layer. This peak at about 450 nm explains the lower luminance for the device with 2% Ir(piq)₃ device. The peak indicates the saturation of phosphorescent emission site due to the low concentration of Ir(piq)₃. The site saturation limits the luminance at high voltage, leading to the steep efficiency drop at high voltage.

Figure 5 shows current density-voltage-luminance curves for the red phosphorescent device with a new electron transport layer. α -NPD layer was used as a hole transport layer. Ir(piq)₃ concentration was 6%.

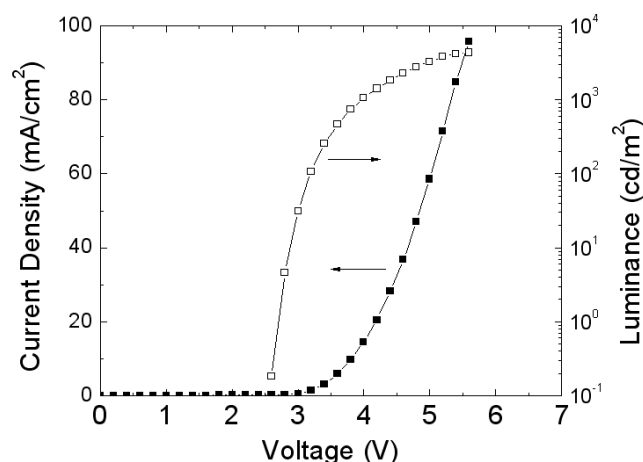


Fig. 5. Current density-voltage-luminance curves for the red phosphorescent devices with new electron transport layer. α -NPD was used as a hole transport layer. Ir(piq)₃ concentration was 8%.

The applied voltage for the current density slightly increases by using an α -NPD layer. The current density of 20 mA/cm² was achieved at an applied voltage of 4.1 V. This increase of applied voltage is due to the voltage distribution in α -NPD layer. With α -NPD layer, additional applied voltage is required to compensation voltage distribution in the organic layers. Due to the slight increase of applied voltage, the driving voltage slight increases. For example, the luminance of 1000 cd/m² is achieved at an applied voltage of 4.0 V. In our CBP:Ir(piq)₃ system, the emission comes out of direct recombination on the Ir(piq)₃ molecules rather than the energy transfer of excitons from the CBP host to the guest molecules. The device shows the current efficiency of about 9 cd/A at a concentration of Ir(piq)₃ 8%. The current efficiency depends on the Ir(piq)₃ concentration. The current efficiency is about 4 cd/A at low concentration,

increasing to about 9 cd/A at about 6 ~ 10 %, and decreasing at higher concentration. The current efficiency was lower than the reported devices. It may be due to the unbalanced electron-hole concentration inside the organic layer. Although the low current efficiency, the low driving voltage leads to the relatively high power efficiency of about 10 lm/W. We believe that the current efficiency can be improved by further optimizing device design.

4. Summary

A luminance of 1000 cd/m² is achieved at a low driving voltage of 2.8 V for the Ir(piq)₃ based red phosphorescent organic light-emitting devices with a new electron transport layer. This low driving voltage is the lowest for the red phosphorescent device as far as we know. This low driving voltage is attributed to the high electron injection/transport properties of new electron transport layer. We expect that the driving voltage can be further lowered by optimizing hole injection and transport properties.

5. References

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