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High Power Efficiency in Blue Phosphorescent Organic Light-Emitting Diodes Using a Spirobifluorene Phosphine Oxide Compound

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High power efficiency blue phosphorescent organic light-emitting diodes (PHOLEDs) were fabricated using a mixed host of 1,1-bis[(di-4-tolylamino)phenyl]cyclohexane (TAPC) and 2,7-bis(diphenylphosphoryl)-9,9'-spirobi[fluorene] (SPPO13) in the emitting layer. A maximum power efficiency of 33.7 lm/W and a high power efficiency of 28.4 lm/W at 1,000 cd/m^2 were achieved in the blue PHOLED with the mixed host emitting layer of TAPC and SPPO13. The efficiency roll-off of the device was also reduced by using the mixed host emitting layer.

Key words blue phosphorescent organic light-emitting diodes; mixed host; high power efficiency; high quantum efficiency

Introduction

Blue phosphorescent organic light-emitting diodes (PHOLEDs) are critical to the power consumption of the organic light-emitting diode (OLED) panel as the current blue fluorescent OLED consumes much power due to the low quantum efficiency of 5∼7%.[1,2] In addition, the rather high driving voltage of the blue device due to the large bandgap of the blue emitting material also increased the power consumption of the OLED. Therefore, the power consumption of the OLED panel can be greatly reduced if the blue PHOLED with high power efficiency can substitute the current blue fluorescent OLED.

There have been many studies to develop high power efficiency blue PHOLEDs with high quantum efficiency and low driving voltage.[3–6] One approach to develop high power efficiency blue PHOLED was to apply host materials which can give high quantum efficiency and low driving voltage.[3,6] Several carbazole type and phosphine oxide type host materials have been reported to be effective to improve the quantum efficiency of the blue PHOLED. The other approach to obtain high power efficiency was to use a mixed host emitting layer structure.[7] High quantum efficiency could be obtained due to balanced charge injection and the driving voltage could be lowered due to efficient charge injection from the charge transport layer to the mixed host emitting layer. In particular, the efficiency roll-off at high luminance could be suppressed in the blue PHOLED with the mixed host emitting layer structure. However, there have been only a few electron transport type host materials for the blue PHOLED[3,7] and further development of the electron transport type host material for the blue PHOLED is required.

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In this work, high power efficiency blue PHOLEDs were developed using a mixed host emitting layer of 1,1-bis[(di-4-tolylamino)phenyl]cyclohexane (TAPC) and 2,7-bis(diphenylphosphoryl)-9,9'-spirobi[fluorene] (SPPO13). The SPPO13 was used as the electron transport type host material and the TAPC was used as the hole transport type host material in the mixed host emitting layer. A maximum power efficiency of 33.7 lm/W and a high power efficiency of 28.4 lm/W at 1,000 cd/m^2 were demonstrated in the blue PHOLED with the TAPC:SPPO13 mixed host emitting layer.

Experimental

The device structure of the mixed host blue PHOLED was indium tin oxide (ITO, 150 nm)/N,N′-diphenyl-N,N′-bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4'-diamine (DNTPD, 60 nm)/N, N′-di(1-naphthyl)-N,N′-diphenylbenzidine (NPB, 20 nm)/TAPC (10nm)/TAPC:SPPO13:iridium(III) bis(4,6-(di-fluorophenyl)-pyridinato-N,C2′) picolinate (FIrpic) (30 nm, 10%)/4,7-diphenyl-1,10-phenanthroline (Bphen, 20 nm)/LiF(1 nm)/Al(200 nm). The compositions of TAPC and SPPO13 in the mixed host were TAPC:SPPO13(100:0, device I), TAPC:SPPO13(75:25, device II), TAPC:SPPO13(50:50, device III), TAPC:SPPO13(25:75, device IV) and TAPC:SPPO13(0:100, device V). Basic device structure and chemical structure of SPPO13 are shown in Figure 1. The relative ratio of the TAPC and SPPO13 was controlled by changing the evaporation rate of the TAPC and SPPO13. The devices were encapsulated with a glass lid and a CaO getter in the glove box after device fabrication. The device performances of the blue PHOLED were measured with Keithley 2400 source measurement unit and CS 1000 spectroradiometer.

Results and Discussion

The two host materials in the mixed host structure should have strong hole and electron transport properties.[8,9] In the case of the TAPC and SPPO13, the TAPC host has strong

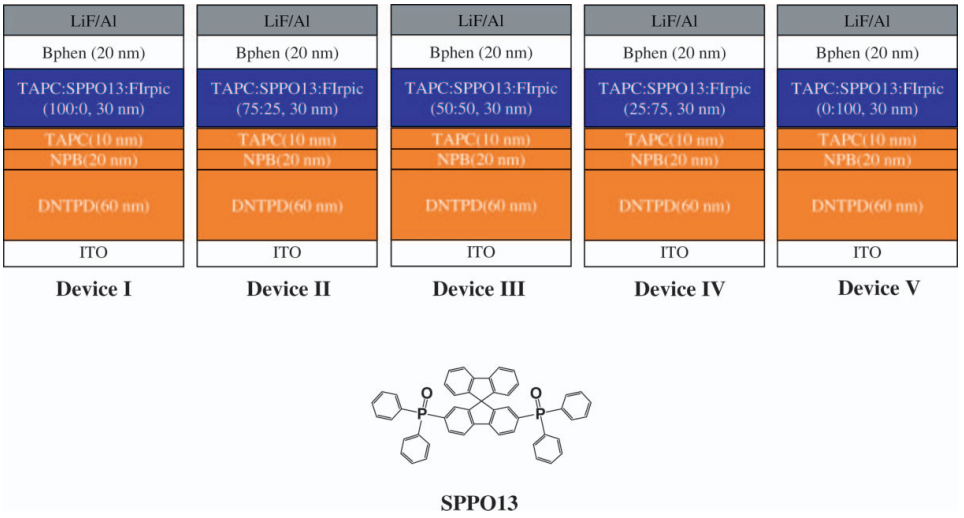

Figure 1. Device structures of blue phosphorescent organic light emitting diodes and chemical structure of SPPO13.

hole transport properties, while the SPPO13 has strong electron transport properties. The TAPC has been known to have a high triplet energy of 2.9 eV for energy transfer to the blue phosphorescent dopant and high hole mobility of 10^{-2} $cm^2/V{\cdot}s$ order.[10] The SPPO13 has a high triplet energy of 2.73 eV and the highly polar phosphine oxide group in the SPPO13 improves the electron transport.[11] Holes can be injected from the hole transport layer to the emitting layer through the TAPC host and electrons can be injected from the electron transport layer to the emitting layer through the SPPO13 host. Therefore, hole and electron injection can be effective in the mixed host blue PHOLED and charge balance in the emitting layer can be managed by controlling the relative composition of the TAPC and SPPO13.

Figure 2 shows the current density-voltage-luminance curves of the mixed host blue PHOLEDs with different host compositions. The current density of the mixed host device was rather low in the device I, while it was similar in other devices. The low current density of the device I with single TAPC host is due to the low electron density in the emitting layer. The TAPC is a strong hole transport type host material and improves the hole injection from the hole transport layer to the TAPC emitting layer. There is no energy barrier for hole

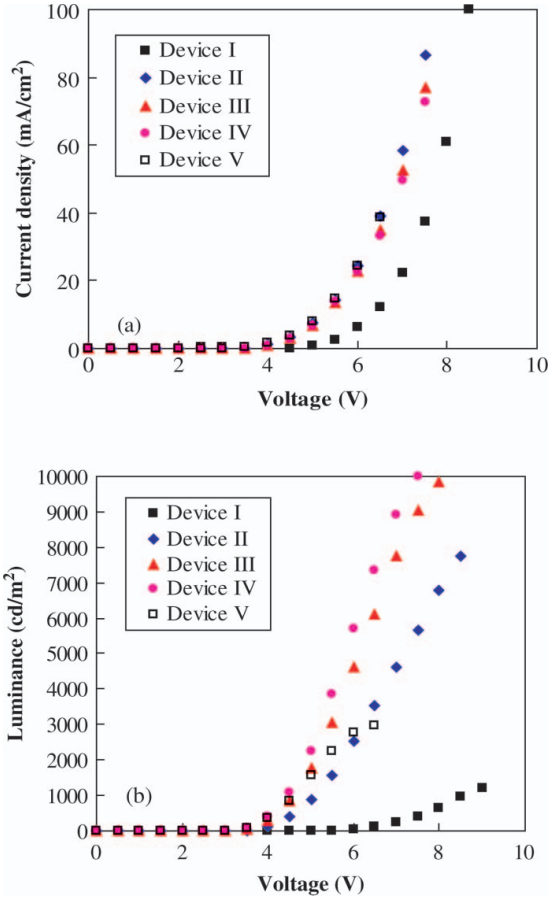

Figure 2. Current density-voltage (a) luminance-voltage (b) curves of the SPPO13 based blue devices according to the host composition.

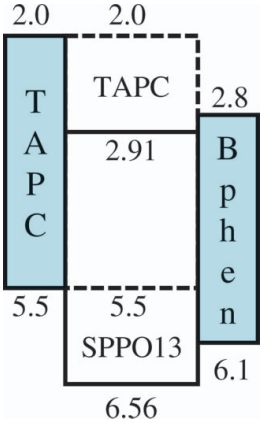

Figure 3. Energy level diagram of the blue phosphorescent organic light emitting diodes.

injection from the TAPC hole transport layer to the emitting layer. However, there is large energy barrier for electron injection from Bphen to the TAPC emitting layer as shown in the energy level diagram in Figure 3. The high energy barrier of 0.8 eV for electron injection limits the electron injection from Bphen to the TAPC emitting layer. Therefore, the current density which reflects hole and electron density in the device was low in the device I. The low current density was increased by adding SPPO13 in the emitting layer. The SPPO13 is an electron transport type host material and the addition of the SPPO13 improved the electron injection from Bphen to the emitting layer. Therefore, similar current density was obtained in the mixed host device due to efficient hole and electron injection.

The luminance of the device was high in the device IV, while it was low in other devices. The luminance is mainly determined by the current density and recombination efficiency of the device. Considering that the current density was similar in all devices except for device I, the high luminance of the device IV is due to high recombination efficiency. The driving voltage of the device IV at 1,000 cd/m^2 was only 4.5 V even without any p type or n type doping structure.[12–14] The use of the mixed host emitting structure lowered the driving voltage due to high luminance caused by the high recombination efficiency. The low luminance of the device I is due to low current density.

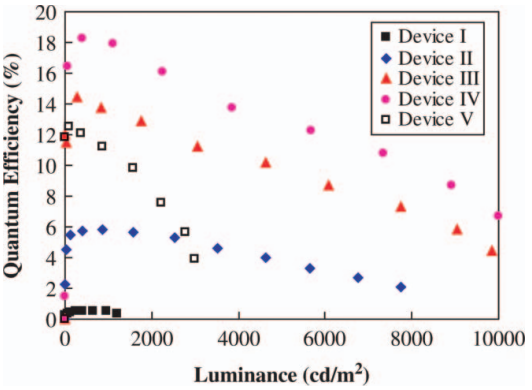

Figure 4. Quantum efficiency-luminance curves of the SPPO13 based blue devices according to the host composition.

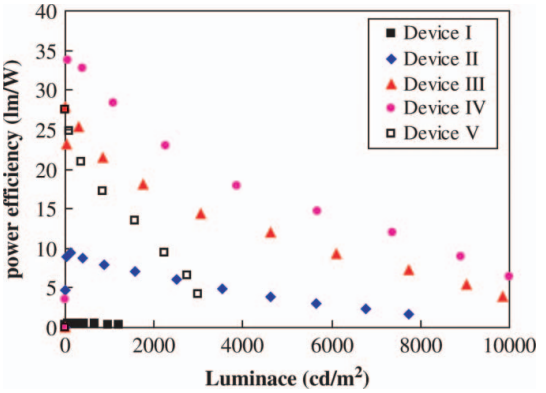

Figure 5. Power efficiency-luminance curves of the SPPO13 based blue devices according to the host composition.

Quantum efficiency-luminance curves of the mixed host devices are shown in Figure 4. The quantum efficiency was increased by using the mixed host emitting structure and the device IV showed the highest quantum efficiency. The maximum quantum efficiency of the device IV was 18.3% at 396 cd/m^2 and the quantum efficiency at 1,000 cd/m^2 was 17.9%. The quantum efficiency was increased by about 50% using the mixed host emitting layer structure. The SPPO13 is an electron transport type host material and the addition of TAPC in the emitting layer improves the charge balance in the emitting layer because of more hole injection into the emitting layer. The TAPC content in the emitting layer was optimized at 25% because of strong hole transport properties of the TAPC. The quantum efficiency was reduced above TAPC content of 25% because of too high hole density in the emitting layer. The holes and electrons were balanced in the device IV.

Power efficiency-luminance curves of the mixed host device are shown in Figure 5. The device IV also showed the highest power efficiency and the maximum power efficiency of the device IV was 33.7 lm/W. The power efficiency was also high at high luminance and the power efficiency at 1,000 cd/m^2 was 28.4 lm/W. The high power efficiency even at high luminance is due to low driving voltage and high quantum efficiency. Other devices showed much lower power efficiency than the device IV because of low quantum efficiency.

Conclusions

High power efficiency blue PHOLEDs could be fabricated using a mixed host structure of hole transport type TAPC and an electron transport type SPPO13 hosts. A maximum power efficiency of 33.7 lm/W and a power efficiency of 28.4 lm/W at 1,000 cd/m^2 could be achieved in the blue PHOLEDs. The improved quantum efficiency and low driving voltage of the mixed host device enhanced the power efficiency of blue PHOLEDs.

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