

# Charge Trapping Host Structure for High Efficiency in Phosphorescent Organic Light-Emitting Diodes

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## Abstract

A charge trapping host structure was developed to improve the light-emitting efficiency of green phosphorescent organic light-emitting diodes. N, N'-dicarbazolyl-3,5-benzene(mCP) and a spirobifluorene based triplet host(PH1) were co-deposited as hosts in the emitting layer and the device performance was examined according to the composition mCP and PH1. The results showed that the quantum efficiency could be improved by 30 % using a mixed host of mCP and PH1.

**Keywords** : mixed host, high efficiency, phosphorescent organic light-emitting diodes

## 1. Introduction

Organic light-emitting diodes(OLEDs) have been on the market for more than 20 years, and many studies have been carried out with the aim of improving their performance. The lifetime and light-emitting efficiency are important characteristics of OLEDs [1-6].

Early work reported that a mixed host structure was effective in improving the lifetime and efficiency of OLEDs[1-7]. The mixed host structure of tris(8-hydroxyquinoline) aluminum(Alq<sub>3</sub>) and N, N'-di(1-naphthyl)-N, N'-diphenylbenzidine (NPB) can significantly enhance the lifetime of OLEDs [1]. The formation of cationic Alq<sub>3</sub> was reduced using the mixed host emitting structure, resulting in an improved lifetime in OLEDs. A similar concept was applied to other OLEDs, and it was found to be quite effective in obtaining a long lifetime and high efficiency[2-8]. The mixed host emitting structure was also reported to improve the efficiency of phosphorescent organic light emitting diodes [9].

In this study, a triplet mixed host system of N, N'-dicarbazolyl-3,5-benzene(mCP) and spirobifluorene based triplet host(PH1), which can trap charges inside the emitting layer, was developed to improve the efficiency of phosphorescent organic light-emitting diodes(PHOLEDs).

## 2. Experiments

The device configuration used in this experiment 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)/NPB(30 nm)/light-emitting layer(30 nm)/biphenoxy-bi(8-hydroxy-3-methylquinoline) aluminum(Balq, 5 nm)/Alq<sub>3</sub>(25 nm)/LiF(1 nm)/Al(200 nm). Five devices were fabricated to investigate the effect of the host composition on the device performance of mixed host devices. Two standard devices with a single host material and three devices with different host compositions were prepared. The total thickness of the light-emitting layer was constant for all devices. Spirobifluorene based PH1 with a linking group between the spirobifluorene units and N, N'-dicarbazolyl-3,5-benzene(mCP) were used as hosts for the EML, and the PH1 content in EML was varied as follows: 0 %, 5 %, 10 %, 25 % and 100 %. Each device was abbreviated as PH1 0, PH1 5, PH1 10, PH1 25 and PH1 100, respectively. PH1, which has a spirobifluorene type backbone structure with high electron transport properties because of the spirobifluorene units, was supplied from Merck Co.. The triplet bandgap of PH1 was 2.4 eV and the highest occupied molecular orbital(HOMO) and lowest unoccupied molecular orbital(LUMO) were 5.9 eV and 2.8 eV, respectively, compared with 6.1 eV and 2.4 eV of mCP, respectively. The triplet energy of mCP was 2.9 eV. The electron mobility of PH1 was  $1.2 \times 10^{-6} \text{ cm}^2/\text{V}\cdot\text{s}$ , as determined from time of flight measurements, but the hole mobility

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could not be determined. Tris(2-phenylpyridine) iridium( $\text{Ir}(\text{ppy})_3$ ) was used as the phosphorescent dopant at a fixed concentration of 5%. The current density-voltage-luminance characteristics of the devices were measured using a Keithley 2400 source measurement unit and a PR 650 spectrophotometer.

### 3. Results and discussion

PH1 and mCP were chosen as the matrix materials for the mixed host PHOLEDs because a mixture of wide bandgap mCP and narrow bandgap PH1 can confine excitons to the emitting layer, and the potential triplet energy transfers from mCP to PH1. It was expected that the dispersion of a narrow bandgap host material in a wide bandgap host material can confine the excitons to the emitting layer, which can increase the recombination efficiency of electrons and holes in the light-emitting layer. Therefore, the device performance of a mixed host system with PH1 and mCP as hosts for the light-emitting layer were investigated according to the relative composition of PH1 and mCP.

Fig. 1 shows the current density-voltage curves of the PH1:mCP mixed host devices according to the relative composition of PH1 and mCP. The PH1 device showed the highest current density, while the mixed host device of PH1 5 exhibited the lowest current density at the same driving voltage. Electron injection from Balq to the host materials is favored in PH1 due to the low energy barrier between PH1 and Balq (0.1 eV), which is in contrast to the 0.5 eV energy barrier between Balq and mCP. Therefore, efficient electron injection from the electron transport layer to PH1 is responsible for the high current density in the PH1 device. On the other hand, the high current density in PH1 25 was

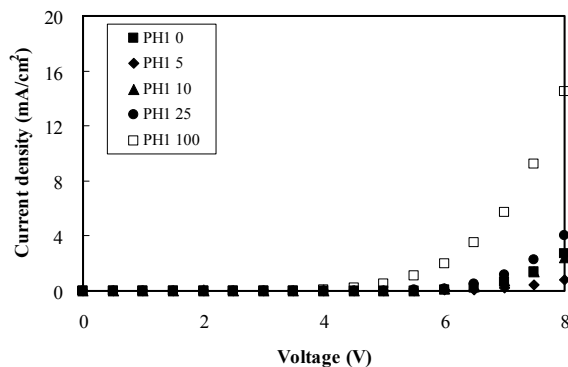


Fig. 1. Current density-voltage curves of phosphorescent mixed host devices.

attributed to the contribution of PH1 to efficient electron injection. The low current density for PH1 5 can be explained by charge trapping in PH1. PH1 is surrounded by mCP in PH1 5, which can result in the trapping of electrons and holes in PH1 due to the 0.4 eV energy barrier for electron injection from PH1 to mCP and the 0.2 eV hole injection barrier from PH1 to mCP. Therefore, the energy barrier suggests that electron transport in the emitting layer is restricted considerably by electron trapping in the PH1 layer, decreasing the current density of the PH1 5 device. The low current density of PH1 10 is also due to electron trapping by PH1.

Fig. 2 is a luminance-voltage plot of PH1:mCP mixed host devices. Luminance is generally determined by the current density, and similar results could be obtained in mixed host devices, even though the PH1 5 and PH1 10 devices showed rather high luminance despite the low current density.

Light emission in the mixed host devices was examined closely by plotting the quantum efficiency as a function of

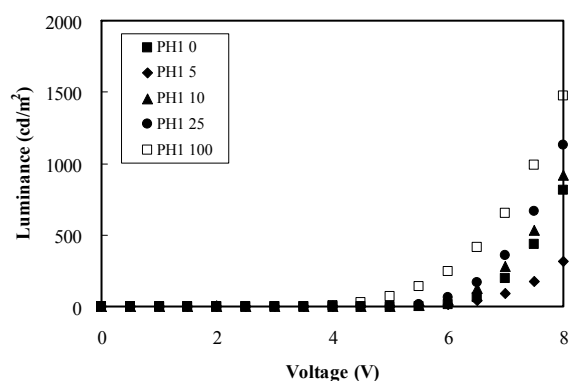


Fig. 2. Luminance-voltage curves of the phosphorescent mixed host devices.

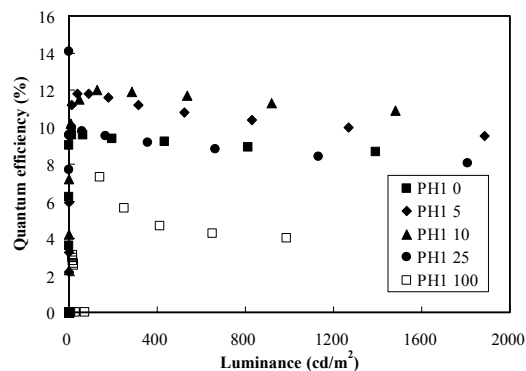
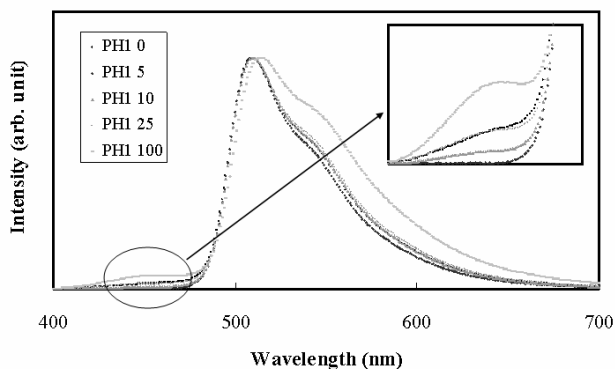


Fig. 3. Quantum efficiency-luminance curves of phosphorescent mixed host devices.

the luminance (Fig. 3). As expected from the luminance-voltage curves, the PH1 10 mixed host device showed the highest quantum efficiency of 11.7 % compared with 3.3 % and 8.7 % for the PH1 and mCP standard devices. There was an approximately 30 % improvement in quantum efficiency in the PH1 10 mixed host device and 25 % enhancement in the PH1 5 device. On the other hand, there was no significant improvement in quantum efficiency in the PH1 25 devices. The high efficiency observed in the PH1 5 and PH1 10 mixed host devices can be explained by exciton confinement in the emitting layer and energy transfer from mCP to PH1. Electrons may be strongly trapped by PH1 because of the large energy barrier between PH1 and mCP. Holes cannot be strongly trapped in PH1 because the difference in the HOMO level difference between PH1 and mCP is only 0.2 eV. Electron trapping by PH1 retards electron transport in the emitting layer, leading to a shift in the recombination zone from the hole transport layer side to the inside light-emitting layer, which will be shown in the electroluminescence spectra of mixed host devices. In addition, the hole and electron balance can be improved in the PH1 10 and PH1 5 devices. Hole injection from the hole transport layer to the emitting layer is difficult due to the hole blocking properties of PH1 and the deep HOMO level of mCP. Therefore, the decreased electron injection in PH1 5 and PH1 10 may improve the charge balance in the light-emitting layer. In PH1 25, the quantum efficiency was rather low compared with the other mixed host devices because the excitons cannot be confined in the emitting layer, and PH1 25 is electron-rich due to the efficient electron injection through PH1.

Fig. 4 shows the electroluminescence spectra of the mixed host devices. The mixed host devices of PH1 5 and



**Fig. 4.** Electroluminescence spectra of phosphorescent mixed host devices.

PH1 10 showed a similar emission spectrum to the standard mCP device in the green wavelength range but a different emission pattern in the blue emission region. The peak maximum of the emission spectra in the mixed host devices was observed at 512 nm, which originated from Ir(ppy)<sub>3</sub> emission. In addition to the main peak, a small emission in the blue region, which was assigned to NPB emission, was observed in the standard mCP and PH1 devices[10]. The intensity of the blue emission was reduced in the mixed host devices, and the PH1 5 device did not show any blue emission. The decrease in blue emission in the mixed host devices suggests a shift in the recombination zone from the hole transport layer side to the electron transport layer side, which can explain the high quantum efficiency in the mixed host devices. As explained in the quantum efficiency data, the recombination zone shift is due to strong electron trapping by PH1 in the emitting layer. A comparison of the quantum efficiency and electroluminescence spectra suggests that PH1 5 should have the highest efficiency because NPB emission was minimized. However, the PH1 10 device showed the maximum efficiency, which also suggests a significant contribution from energy transfer from mCP to PH1 and the charge balance. The red shift in green emission above 520 nm in the PH1 10 device reflects the emission from the PH1:Ir(ppy)<sub>3</sub> system. In PH1 5, there was no change in the emission spectrum from mCP emission except for the disappearance of the blue emission at approximately 450 nm. The emission spectra and quantum efficiency show that PH1 plays the role of an electron trapping material in PH1 5, while it acts as both an electron trapping material and a host for the green dopant in PH1 10.

#### 4. Conclusions

The quantum efficiency of green PHOLEDs could be improved using a mixed host device structure, which can confine the excitons in the light-emitting layer. A mixed host device with a wide bandgap host material as the main component and a narrow bandgap host as the minor component showed enhanced device performance due to exciton confinement, low electron leakage and improved charge balance.

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