

Electrical Characteristics of Green Emitting Phosphor Ir(PPY)₃ Doped OLEDs

Junho Kim, Yun-Myung Kim, Yunkyung Ha, Young-Kwan Kim and Jung-Soo Kim

Abstract -The organic light-emitting devices (OLEDs) based on fluorescence have low efficiency due to the requirement of spin-symmetry conservation. By using the phosphorescent material, internal quantum efficiency can reach 100%, compared with 25% in the case of the fluorescent material. Thus, phosphorescent OLEDs have recently been extensively studied and shown higher internal quantum efficiency than the conventional OLEDs. In this study, we investigated the characteristics of the phosphorescent OLEDs with the green emitting phosphor, Ir(ppy)₃ (tris(2-phenylpyridine)iridium). The device with a structure of ITO/TPD/Ir(ppy)₃ doped in BCP/BCP/Alq₃/Li:Al/Al was fabricated, and its electrical and optical characteristics were studied. By changing the doping concentration of Ir(ppy)₃, we fabricated several devices and investigated their characteristics.

Keywords - OLEDs, phosphorescence, Förster transfer, Dexter transfer, power efficiency

1. Introduction

Organic light-emitting devices (OLEDs) have been studied for a promising flat panel display. After Tang reported bright green emitting diodes, using a fluorescent material Alq₃, a wide range of luminescent materials has been reported by many research groups[1]. Despite many efforts, the radiative process of fluorescence is less efficient as approximately 75%, due to the requirement of spin-symmetry conservation[2].

Spin-symmetric excitons with a total spin of $S = 1$ are known as triplets, and spin-antisymmetric excitons ($S = 0$) are known as singlets. During electrical excitation, approximately one singlet exciton is created for every three triplet excitons. Because the ground state is also spin-antisymmetric, however, only singlet excitons can decay to generate fluorescence, conserving spin symmetry. Usually triplets in organic molecules are wasted via nonradiative decay at room temperature. However, given some perturbation in spin-symmetry, triplets may slowly undergo a radiative decay, producing delayed luminescence known as phosphorescence. Using this concept, S. R. Forrest et al. recently showed a possibility of highly efficient OLEDs with phosphorescent materials doped into fluorescent host materials[3-4]. Dye-doped OLEDs represent one of the methods that may improve efficiency by energy transfer from the host to the dye. When a bias is applied to OLEDs, carriers are injected

into the organic film from the two electrodes, and then generate excitons in the emitting layer. These excitons are relaxed radiately or may transfer their energy to the dye. Thus, the luminescent characteristics of the dye are reflected in the resulting luminescence spectrum of the device.

There are two mechanisms in energy transfer from the host material to the guest dye. One of them is Förster transfer involving strong coupling between the transition dipole moments of the exciton and the dye, and thus its available range is up to 50~80 Å. Förster energy transfer is useful only to the fluorescent dye[5]. Another energy transfer mechanism is Dexter energy transfer which is a dominant mechanism in phosphor doped OLEDs. In Dexter energy transfer, spin symmetry does not matter, and the energy transfer range of about 10-15 Å is shorter than that of Förster energy transfer[5]. That is why the doping concentration of the phosphorescent dye should be higher than that of the fluorescent dye[6].

In this paper, we investigated the electrical and optical characteristics of phosphorescent OLEDs using a phosphor Ir(ppy)₃, with the optimized doping concentration.

2. Experimental

For the study, we fabricated the multi-layer phosphorescent OLEDs containing the emitting layer of Ir(ppy)₃ [tris(2-phenylpyridine)iridium] doped into BCP.

The fabrication details are as follows : ITO (indium-tin-oxide, sheet resistance: 30 Ω /□) coated glass substrates were cleaned in the ultrasonic bath of chloroform, acetone, methanol, and isopropyl alcohol,

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consecutively, and then rinsed with the distilled water. After drying, the substrates were loaded in a deposition chamber for successive thermal deposition of the organic and metal layers under 5×10^{-6} Torr. The deposition rates were $0.5 \sim 1$ Å/s and $5 \sim 10$ Å/s for organics and metals, respectively. To find the proper doping concentration, we fabricated several devices, by varying the doping concentration of Ir(ppy)₃ as 5, 10, 17, and 33 %. Fig. 1 shows the organic materials used in the fabrication of OLEDs in this study.

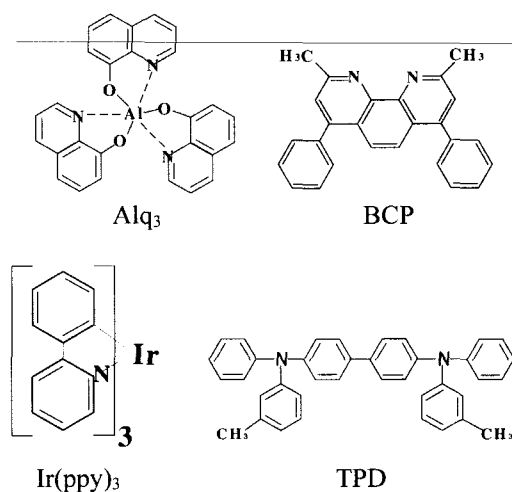


Fig. 1 Materials used in this study.

The configuration of the OLEDs manufactured in this study is shown in Fig. 2. The structure of the multi-layer OLEDs was shown as follows: glass substrate/ITO/HTL (TPD = 40nm)/EML (Ir(ppy)₃ doped in BCP = 30nm)/HBL (BCP = 10nm)/ETL (Alq₃ = 40nm)/Li:Al (100nm)/Al (100nm), where HBL stands for the hole blocking layer[7]. The device area was 5×5 mm² and all measurements were performed in ambient conditions under the forward DC voltage bias. To investigate UV/vis absorption and photoluminescence [PL] characteristics, other samples of the organics thermally deposited on the quartz were prepared.

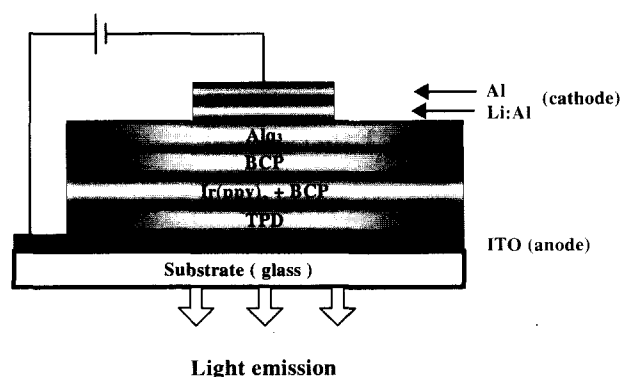
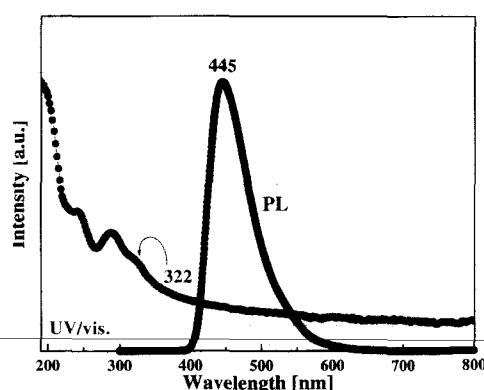
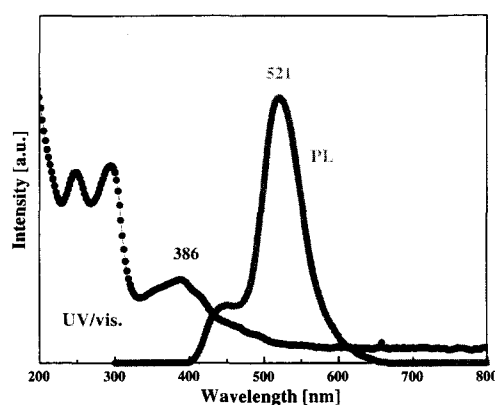


Fig. 2 Configuration of the OLEDs used in this study.

3. Results and Discussion



(a)



(b)

Fig. 3 UV/vis absorption and PL spectra of (a) BCP, and (b) Ir(ppy)₃.

Fig. 3 shows the UV/vis absorption and PL spectra of the host material BCP, and the phosphor dye Ir(ppy)₃. As shown in Fig. 3, the PL peak of BCP is overlapped with absorption peak of Ir(ppy)₃, indicating that energy transfer from BCP to Ir(ppy)₃ will be efficient. The PL peaks of BCP and Ir(ppy)₃ were centered at 445 nm and 521 nm, where blue and green lights emit, respectively.

As shown in Fig. 4, the electroluminescence [EL] spectra of the devices with and without Ir(ppy)₃ were compared to define the luminescent center. The device without Ir(ppy)₃ emits green light (centered at 509 nm and originated from Alq₃) as well as blue light (centered at 459 nm and originated from BCP). On the other hand, the device with Ir(ppy)₃ doped in BCP emits only green light centered at 520 nm. Thus, we concluded that there was no emission from the BCP or Alq₃ layer in the device with Ir(ppy)₃/BCP. The excitons formed in BCP instead transferred energy to Ir(ppy)₃ efficiently, resulting in the emission of Ir(ppy)₃ and exhibiting its own characteristic spectrum.

To achieve high efficiency, we fabricated several samples by varying phosphor doping concentration, and found 10 % doping concentration was the best.

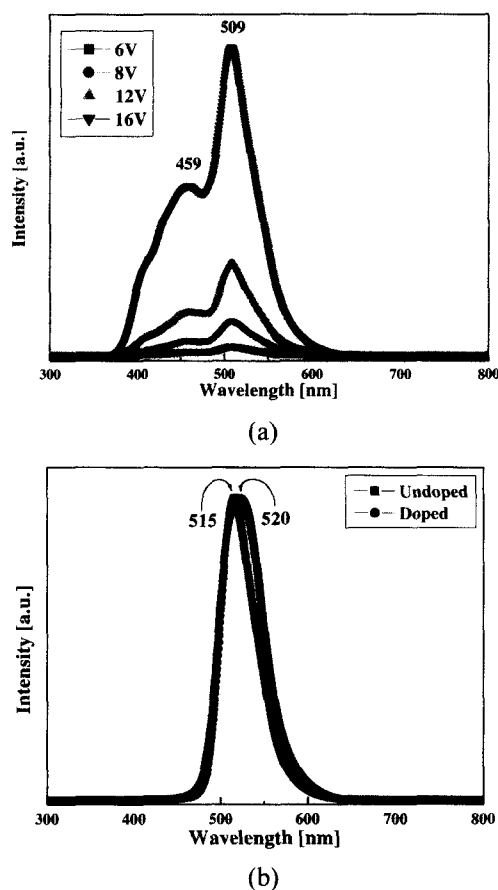


Fig. 4 EL spectra of the devices without Ir(ppy)₃ (a) and with Ir(ppy)₃ (b): The driving voltage did not affect the EL spectra of the doped OLEDs.

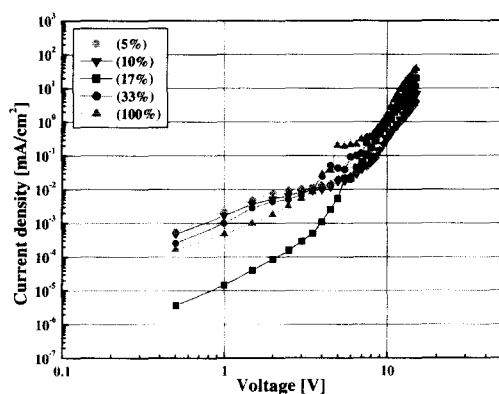


Fig. 5 J-V characteristics of OLEDs depending on doping concentration

Fig. 5 shows the J-V characteristics of OLEDs depending on doping concentration. From the J-V characteristics, we observed that the turn-on voltage is near 5V for all samples and current density is decreased in the emission region as doping concentration decreases. In the low voltage region, Ir(ppy)₃ molecules in the BCP matrix play a role of traps, and thus carriers are trapped in Ir(ppy)₃, resulting in lower current density. As voltage increases, however, the trapped carriers in Ir(ppy)₃ are

released by a high electric field. Thus, current density can be high. Since there are few traps in the lightly doped device, compared with the heavily doped device, only a few trapped carriers are regenerated with high electric fields.

We measured device luminance and calculated power efficiency from the following equation:

$$\eta = [\pi \times L] / [J \times V],$$

where L is luminance and J is current density.

The 10% doped device showed the highest luminance and power efficiency among the device samples. Although the luminance characteristics of the samples were similar, the characteristics of power efficiency were found to be different since the current density of the devices that affects power efficiency is lower in the 10% doped sample than in the other samples. Consequently, the power efficiency of the 10% doped device was 7 times higher than that of the undoped device.

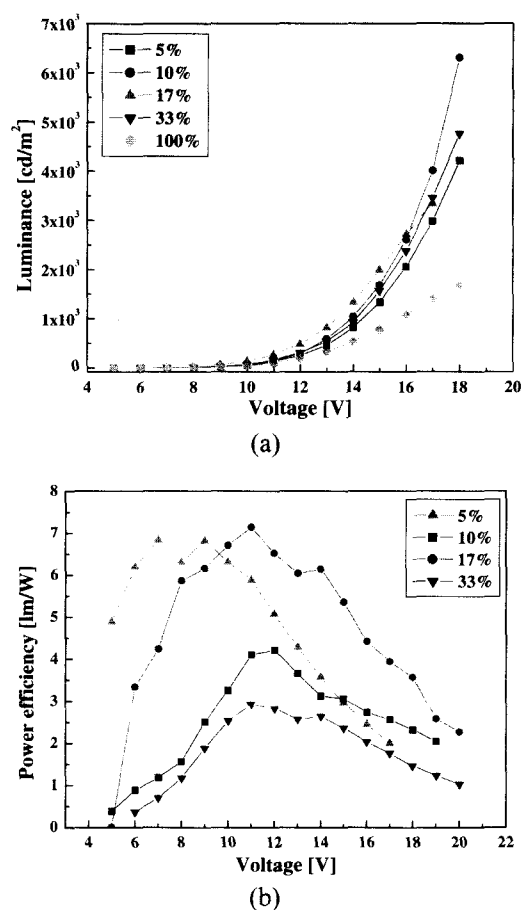


Fig. 6 L-V characteristics (a) and power efficiency (b) of the devices with various doping concentration

As shown in Fig. 6, power efficiency decreases abruptly as voltage increases. It is caused by triplet-triplet annihilation which occurs in the process of phosphorescence especially at high excitation density. In

this triplet quenching process, two triplets combine to form a singlet and a ground state molecule: $T_1 + T_1 \rightarrow S_1 + S_0$ [5].

Fig. 7 shows the energy diagram of the OLEDs fabricated in this study. When the forward DC bias is applied, holes from ITO anodes and electrons from Li:Al cathodes are injected into HTL and ETL, respectively. These carriers are then transported through their respective transporting layers, and excited either in BCP where the resulting excitons transfer energy to Ir(ppy)₃ efficiently or in Ir(ppy)₃ directly. Finally, excitons in BCP decay nonradiatively after energy transfer while Ir(ppy)₃ emits green light centered at 515 nm. BCP as HBL(hole blocking layer) can restrict hole transport to ETL, and thus increases the probability of exciton formation in BCP of EML(emitting layer).

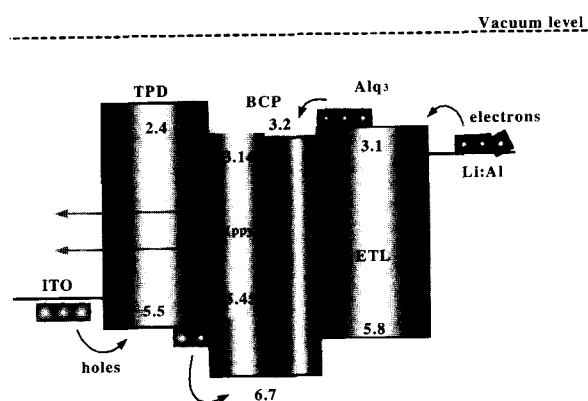


Fig. 7 Energy diagram scheme of the OLEDs fabricated in this study.

4. Conclusion

For wide applications of OLEDs, high efficiency must be achieved. Phosphorescence has an advantage in that triplets are not wasted anymore. Thus, the internal quantum efficiency of OLEDs can reach approximately 100% theoretically. Dye-doped OLEDs are usually more efficient because the quantum efficiency of the dispersed dye is relatively higher than the dense host where the dye is doped into.

We fabricated phosphorescent Ir(ppy)₃ - doped OLEDs and showed improvement in power efficiency compared with undoped OLEDs. The power efficiency of 10% Ir(ppy)₃ - doped OLEDs is 7 times higher than the neat film OLEDs. Since triplet-triplet annihilation causes self-quenching of excitons at high excitation density, power efficiency decreases abruptly as voltage increases.

We now continue to find proper host materials that can efficiently transfer energy to the phosphorescent dye efficiently. The synthesis of several other phosphorescent materials that emit red and blue lights is in progress for full color display applications in our laboratory as well.

Acknowledgment

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