Luminance Enhancement of the OLED by Direct Emission of Circular Polarization

Dong-Myoung Lee¹, Jin-Hyang Jung¹, Byung-Jun Kang¹, Yoonseuk Chof², Chang-Jae Yu¹ and Jae-Hoon Kim¹,²

¹Department of Electronics and Computer Engineering, Hanyang University, Seoul 04763, Korea
²Department of Electronics and Control Engineering, Hanbat National University, Seoul 04763, Korea

Abstract
We report an enhancement of the OLED luminance by using a circularly polarized electroluminescence (CPEL). The CPEL was directly achieved in the conjugate polymer twisted by doping a chiral agent to an emitting material. Under circular polarizer for antireflection, the luminance efficiency was enhanced by 30%.

Author Keywords
polarized OLED, high brightness, twisted conjugated polymer

1. Introduction
The organic electroluminescence (EL) phenomena have been studied for a display application of an organic light-emitting diode (OLED), since their excellent characteristics such as low voltage driving, high brightness, and good color performances [1]. Especially, the polymer light-emitting diodes (PLEDs) based on a solution process have attracted much attention due to low cost fabrication [2]. However, the luminance improvement of the OLED is required due to low external quantum efficiency and circular polarizer for anti-reflection. Therefore, luminance enhancement of the OLED has attracted much attention in display applications. The direct emission of circularly polarized (CP) light is one candidate for improving the luminance efficiency of the OLEDs [3]. The polarized emission is strongly influenced by the orientation of the conjugated polymer [3-5].

In this work, we report an enhancement of the OLED luminance by a CP electroluminescence (CPEL). The direct emission of the CPEL was achieved by introducing continuously twisted configuration of the mesogenic conjugate polymer by doping a chiral agent to the emission material. The twisted configuration gives rise to the degree of the CPEL, defined by the dissymmetry g-factor $g = 2 (I_L - I_R) / (I_L + I_R)$, where $I_L$ and $I_R$ represented by the intensities of left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP), respectively. It should be noted that $0 \leq |g| \leq 2$, and higher $|g|$ value implies higher circular polarization, and thus luminance efficiency increases under external circular polarizer for antireflection. In our experiment, we observed 30% enhancement in the luminance efficiency.

2. Experimental
Figure 1 shows a schematic diagram of our device and chemical structure of the materials. The emitting materials consist of the poly(9,9-di-n-octylfluorenyl-2,7-diyi)alt-(benzo[2,1,3]thiadiazol-4,8-diyl) (F8BT) for emitting material and right-handed chiral dopant, R5011 (E. Merck) to form a twisted configuration. The hole blocking material, 2,2’′,2′′′-(1,3,5-benzentriyl)tris(1-phenyl-1H-benzimidazole) (TPBi) and the hole injection material, copper phthalocyanine (CuPc) were used, and the planar alignment layer, AL22636 (JSR) was served as the hole transport layer (HTL) and electron blocking layer (EBL). The CuPc with thickness of 2 nm was deposited by thermal evaporation for hole injection on an indium-tin oxide (ITO) anode high-vacuum (6 x 10⁻⁶ torr). Next, AL22636 as the HTL/EBL and alignment layer was deposited by spin coating for 20 nm onto the ITO substrate. Noted that no rubbing process was required. The chiral dopant R5011 was added to the F8BT with a nematic liquid crystal phase. The F8BT mixture dissolved in toluene was spun-coated on the AL22636 layer for 200 nm. The prepared substrate was annealed at nematic temperature of (TOPCON, SR-UL 1R). The birefringence of the F8BT film was measured using the photo-elastic modulator (PEM) (Hinds, PEM-100) and lock-in amplifier (SRS, SR830) based on the PEM method [6]. All fabricating processes were carried out in a glove box filled with N₂ gas and encapsulated by glass and UV curable resin (NOA 65, Norland Products) to avoid exposure to humidity and oxygen.

The PL and EL were measured using a spectroradiometer (TOPCON, SR-UL 1R). The birefringence of the F8BT film was measured using the photo-elastic modulator (PEM) (Hinds, PEM-100) and lock-in amplifier (SRS, SR830) based on the PEM method [6]. All fabricating processes were carried out in a glove box filled with N₂ gas and encapsulated by glass and UV curable resin (NOA 65, Norland Products) to avoid exposure to humidity and oxygen.
3. Result & Discussion

Figure 2 shows CP photoluminescence (CPPL) and CPEL spectra of the pure F8BT and the doped F8BT with the chiral agent under different circular polarizers. Here, the total intensity without any polarizer, the RHCP intensity, and the LHCP intensity are depicted by $I_T$, $I_R$, and $I_L$, respectively. As shown in Figs. 2(a) and (b), in the case of the pure F8BT on the unrubbed alignment layer, $I_R$ and $I_L$ were equivalent to each other in both CPPL and CPEL. On the contrary, in the case of the doped F8BT with R5011, the RHCP intensity $I_R$ is about 2 times higher than the LHCP intensity $I_L$ as shown in Figs. 2(c) and (d). It should be noted that sum of two orthogonal CP lights is almost matched to the total intensity as shown in Fig. 2. In our EL device, the dissymmetry $g$-factor at 546 nm was measured to be 0.63 and thus the luminance enhancement is about 30% compared to EL device under an external RH circular polarizer for eliminating reflection of ambient light.

Figure 2 (a) CPPL and (b) CPEL spectra of the pure F8BT film on unrubbed alignment layer, and (c) CPPL and (d) CPEL spectra of the doped F8BT film on the unrubbed alignment layer, respectively. $I_T$, $I_R$, and $I_L$ represent the total intensity without polarizer, the intensities of the RHCP and the LHCP light, respectively.

Figure 3 shows angular dependent retardation as a function of the rotation angle with respect to one of closed polarizers in the PEM method [6]. The anisotropic conjugated polymer would be properly aligned along the rubbing direction and continuously twisted along the normal direction of the substrate due to the chiral dopant. The doped F8BT on the rubbed alignment layer exhibited very high $g$ factor [3] and thus large enhancement of the EL was expected. However, additional optical design should be required to eliminate the reflection of ambient light because of birefringence of the emitting layer as shown in Fig. 3(a). On the other hand, in the case of the unrubbed alignment layer, the birefringence was significantly smaller than that of rubbed alignment layer as shown in Fig. 3(b). In the pure F8BT films without the chiral dopant, a large birefringence was observed in the case of the rubbed alignment layer but small birefringence was measured in the case of the unrubbed alignment layer as shown in Fig. 3(c). Our device structure proposed here does not generate the birefringence across whole device and thus additional optical design is not required. Although no birefringence is observed, the dissymmetry of the CPEL was achieved in our device structure. This would be derived from the microscopic twisted structure of the F8BT by the chiral dopant with high helical twisting power. Each microscopic twisted structure was formed with a different azimuthal direction on the unrubbed alignment layer but the twisted angle and handedness were equivalent in all microscopic twisted domains. It should be noted that the CP intensity is independent of the azimuthal direction. As a result, no birefringence is measured in our OLED device and thus additional optical design is not required to eliminate the reflection of ambient light.

Figure 3 Angular dependent retardation (symbols) and the fitted result (solid lines) of the F8BT/R5011 films on (a) the rubbed alignment layer and (b) the unrubbed alignment layer. (c) Maximum retardation of the various F8BT films.

Figure 4 shows an experiment setup for measuring the reflectance of the ambient light and the reflectance of the various F8BT films. To measure the reflectance of the ambient light, the circular polarizer consisting of the linear polarizer and the quarter-wave plate was placed between the light source and the F8BT film as shown in Fig. 4(a). In this experiment setup, the reflected light from a mirror was completely blocked by the circular polarizer if there is no retardation in the F8BT film. No reflectance means to eliminate the ambient light completely. As you expect, in the cases of the rubbed alignment layer in both F8BT films with/without chiral dopant, large intensities of reflectance were measured. On the other, very small intensities were measured in the unrubbed alignment layers regardless of the F8BT films with/without chiral dopant. To eliminate the
reflectance of the ambient light. No additional optical design is required.

Figure 4 (a) Experiment setup and (b) reflectance measured under a circular polarizer.

Figure 5 shows EL images fabricated with pure F8BT and doped F8BT on unrubbed PI under no polarizer, the RH and the LH circular polarizer, respectively. In the pure F8BT sample, the brightness under RH circular polarizer is almost similar to that under LH circular polarizer as shown in Fig. 5(a). In the doped F8BT sample with the R5011, on the other hand, it can be clearly seen that the image under RH circular polarizer is brighter than that under LH circular polarizer. As a result, the brighter lumiance was achieved by introducing the chiral dopant to the F8BT under an antireflection condition of ambient light (RH circular polarizer).

4. Conclusion
We reported an enhancement of luminance efficiency in the OLEDs by the direct emission of the CPEL. Under circular polarizer for antireflection of ambient light, we achieved 30% enhancement in the luminance efficiency. In addition, any optical design for anisotropic emitting polymer is not required to eliminate the reflection of the ambient light since there is no birefringence in the whole device even containing mesogenic conjugate polymer. We expect that this approach is applicable to other luminance-enhancing processes such as light extracting method, and is viable to enhance the luminance of the conventional OLEDs.

5. References