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Ji-Geun Jang<sup>a</sup>, Hee-Won Kim<sup>a</sup>, Jong-Myung Ahn<sup>a</sup>  
& Sang-Baie Shin<sup>a</sup>

<sup>a</sup> Department of Electronics Engineering, Dankook University, Chungnam, Korea

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## New White OLED Using Selective Doping in a Single Host

Ji-Geun Jang, Hee-Won Kim, Jong-Myung Ahn,  
and Sang-Baie Shin

Department of Electronics Engineering, Dankook University,  
Chungnam, Korea

*A new white emitting OLED (WOLED) using selective doping in a single host is proposed. The device had the structure of ITO/2-TNATA/NPB/GDI-602/GDI602:rubrene/Alq<sub>3</sub>/LiF/Al, in which the GDI602/GDI602:rubrene emission layer was prepared by the selective doping of rubrene into the single GDI-602 host material. The blue and yellow emitting regions consisted of GDI-602 that was undoped and doped with rubrene (10% of the host material in the evaporation rate), respectively. The luminance and efficiency of the fabricated device were 1050 cd/m<sup>2</sup> and 0.6 lm/W at the driving voltage of 9 V, respectively. It showed two peak wavelength emissions of 460 nm and 560 nm in the electroluminescent spectra. The color coordinate in the CIE chart was (0.33, 0.33) which proved to be pure white emission.*

**Keywords:** GDI-602; rubrene; selective doping; white organic light emitting diode (WOLED)

## INTRODUCTION

WOLEDs can be used as a backlight for LCDs [1] and also as a light source for full color displays [2,3] in which red, green, and blue subpixels are easily obtained without conventional shadow masking processes by using color filters. The methods of realizing full color displays include side-by-side arrays of R/G/B subpixels, blue emission with color conversion layers, and white emission with color filters [4,5]. The side-by-side method is the most widely used nowadays, but it has problems such as a low red efficiency and poor blue purity.

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Address correspondence to Ji Geun Chang, Department of Electronics Engineering, Dankook University, San 29, Anseo-dong, Cheonan, Chungnam 330-714, Korea (ROK). E-mail: semicgk@dankook.ac.kr

The mechanisms of multilayer white emission include the combination of R/G/B colors and the combination of blue and yellow emissions [6,7]. The R/G/B three color mixing method has been considered as one of the best methods for generating white light, but it has low efficiency and unstable interference, so that the mixing of two colors is now considered to be a more viable technology. The two color (or wavelength) method shows high emission stability and has a simpler fabrication process in comparison with the three color mixing method.

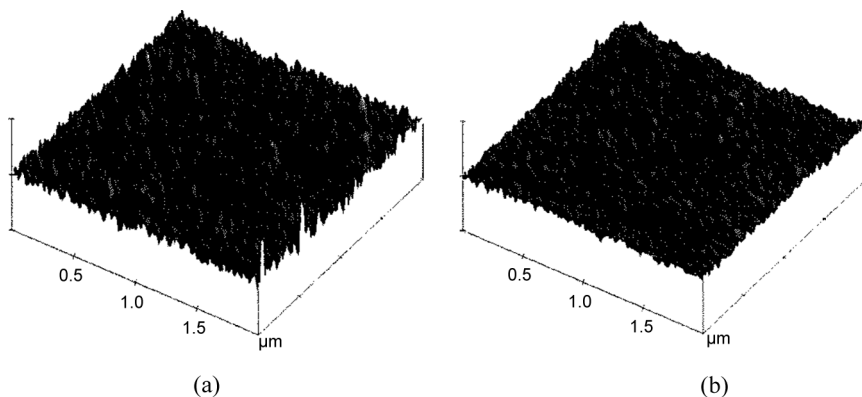
The emission characteristics of OLEDs are greatly affected by the formation and treatment of the electrodes, carrier injection and transport materials, and phosphor system in the fabrication process. In addition, good interfaces between the layers in the device structure, especially between the ITO electrode and the hole injection layer, are necessary for the development of high quality OLEDs [8,9]. Since organic materials are very susceptible to deterioration by oxygen or humidity [10,11], high vacuum *in-situ* processing is also indispensable to fabricate good performance OLEDs.

In this study, new dual wavelength OLEDs having GDI602 as the blue emission material and GDI602: rubrene as the yellow emission material are introduced and their efficiencies, color purities, and electrical stabilities were investigated. The selective doping technique of rubrene in a single blue host as the white emitting system proposed in this study enables us to fabricate new WOLEDs with a simple structure and high performance.

## EXPERIMENTAL PROCEDURE

Glass coated with 1500Å-ITO with a sheet resistance of  $12\Omega/\square$  was used as a substrate. AZ1512-photoresist was coated on the substrate at 2500 rpm for 30 seconds to pattern the ITO electrodes. The remaining solvent was removed by soft baking for 20 minutes at 80°C. After UV exposure with an anode mask, developing was performed for 60 seconds using AZ500, followed by hard baking for 30 minutes at 80°C. Etching of ITO was performed at 60°C using MAS02 solution. The remaining photoresist was completely removed by acetone. Ultrasonic degreasing using isopropyl alcohol and DI water were successively performed. Then, the cleaned substrate was dried and moved to the glove box before loading it into the vacuum deposition system.

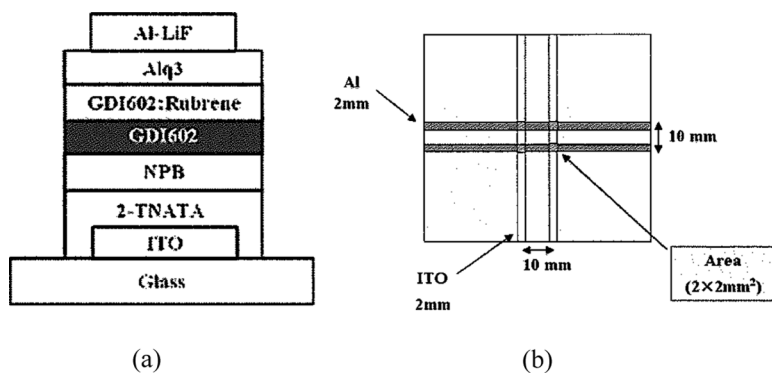
The organic thin layers and metallic layer were deposited under a pressure of  $5 \times 10^{-8}$  Torr-using the *in-situ* method. Before the deposition of the organic layers, the substrate was plasma-treated at 200 W for two minutes under a pressure of  $O_2/Ar(50\%)$  of 1 mTorr. The preliminary plasma treatment in the fabrication of OLEDs is



**FIGURE 1** ITO surface images: (a) before and (b) after plasma treatment.

expected to reduce the energy barrier for hole injection from the anode and remove surface contaminations, as well as improving the adhesion between the ITO and the organic hole injection layer. Figure 1 shows the atomic force microscope (AFM) images of the ITO surface before and after the plasma treatment. The root mean square values of the surface roughness before and after the plasma treatment were 1.58 nm and 1.06 nm, respectively. The root mean surface roughness of the ITO electrode was shown to decrease after the plasma treatment.

After the substrate was moved from the plasma chamber into the high vacuum organic chamber, 2-TNATA[4,4',4''-tris(2-naphthylphenyl-phenylamino)-triphenylamine] and NPB [N,N'-bis(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine] with thicknesses of 600 Å



**FIGURE 2** Structure of the fabricated device: (a) stacked film layers and (b) layout on the substrate.

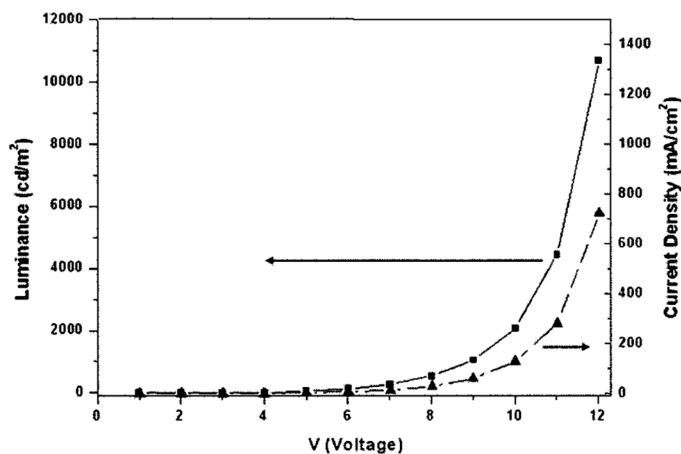
and 250 Å were successively deposited as a hole injection layer (HIL) and hole transport layer (HTL), respectively. In the formation of the emitting materials, 70 Å-thick GDI602 was deposited without doping. Then, GDI602:rubrene at a ratio of 10:1 were co-evaporated with a thickness of 220 Å. Finally, the electron transport layer (ETL) consisting of 300 Å-thick Alq<sub>3</sub> and cathode consisting of 10 Å-thick LiF and 1800 Å-thick Al were successively deposited. Figure 2 shows the deposited film layers and layout of the fabricated device. In Figure 2, four OLED devices are integrated on one substrate and the light emission area of the unit device is 2 mm × 2 mm.

## RESULTS AND DISCUSSION

The electrical and optical characteristics of the fabricated samples were evaluated using an HP4145B semiconductor parameter analyzer and CS-1000 spectro radiometer.

Figure 3 shows the L-V-J (luminance-voltage-current density) characteristics of the fabricated device. In Figure 3, the current density increases exponentially with increasing applied voltage, which is the typical behavior of a diode. The current density-voltage characteristics are similar to the luminance-voltage characteristics, because the OLED is a current driving device. The fabricated device showed a threshold voltage of 4 V based on a luminance of 10 cd/m<sup>2</sup> and a pure white luminance of 1050 Cd/m<sup>2</sup> at 9 V.

The luminance efficiency( $\eta$ ) can be calculated by the equation  $\eta = (\pi L) / (VJ)$  if the current density-voltage and luminance-voltage



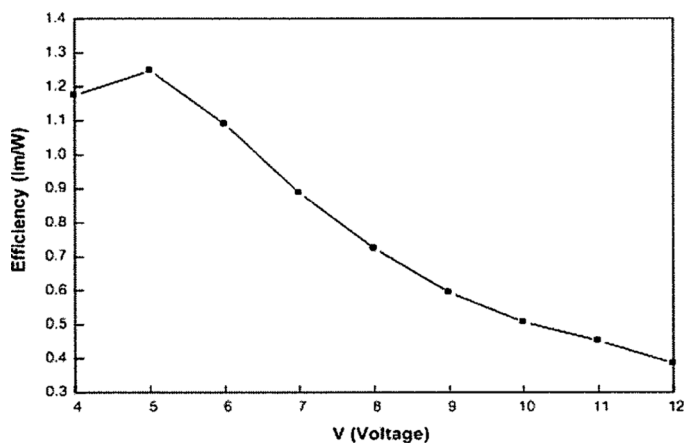
**FIGURE 3** L-V-J (Luminance-Voltage-Current density) characteristics.

relationships are known, where  $L$  ( $\text{cd/m}^2$ ),  $V$  (V), and  $J$  ( $\text{A/m}^2$ ) are the luminance intensity, applied voltage, and current density, respectively.

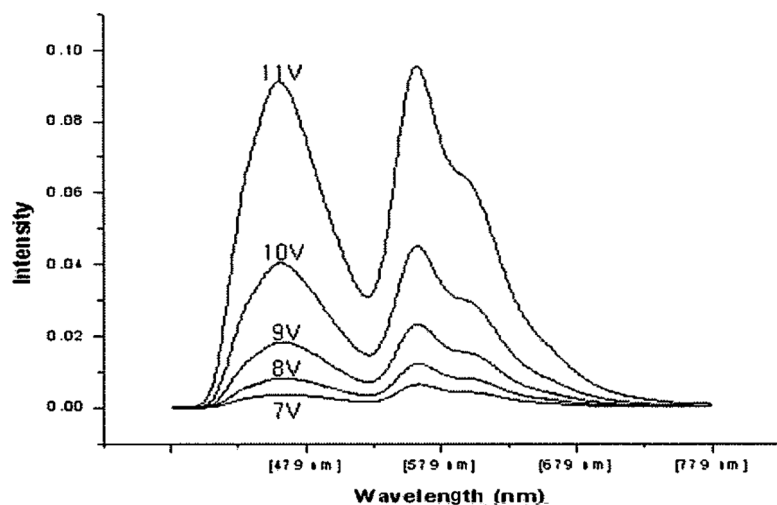
Figure 4 shows the power efficiency-voltage characteristics based on the calculations performed using this equation. The efficiency above 5 V tended to decrease monotonously as the applied voltage increased. The decrease of the efficiency with increasing voltage was due to the linear relation between the current and luminance. The power efficiency at 9 V was 0.6 lm/W.

The emission spectra of the fabricated device shown in Figure 5 has two constant peak wavelengths (460 nm and 560 nm) at all applied voltages. However, the relative intensity of blue light to yellow light gradually increased as the applied voltage increased. This explains why the fabricated device exhibited a blue shift in its overall color as the applied voltage increased. Figure 6 shows the variation of the CIE (Commission Internationale de l'Eclairage) coordinates with the applied voltage. The color coordinates at applied voltages of 7 V, 9 V, and 11 V were (0.37, 0.37), (0.33, 0.33), and (0.32, 0.32), respectively. The CIE coordinate of (0.33, 0.33) belongs to pure white, so that the fabricated device is shown to generate pure white color at an applied voltage of 9 V, as shown in Figure 7.

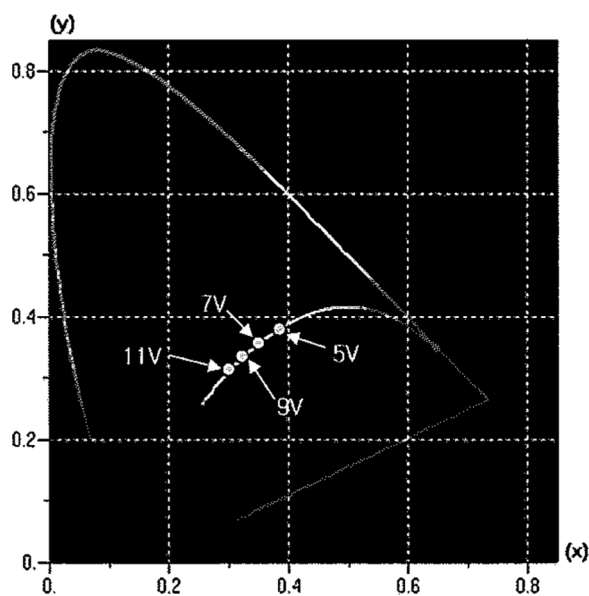
The new WOLED with a simple structure and high quality white emission was successfully fabricated using the selective doping of rubrene into a single host of GDI-602 as the emitting system in this research.



**FIGURE 4** Power efficiency-voltage characteristics.

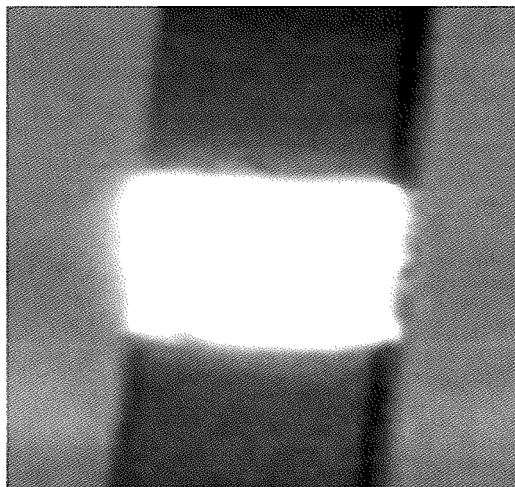


**FIGURE 5** EL spectra with the parameters of applied voltages.



**FIGURE 6** CIE coordinates at several applied voltages.





**FIGURE 7** Pure white light emission at the applied voltage of 9 V.

## CONCLUSIONS

A new white OLED using selective doping into a single host was proposed for the first time in this research. The structure of the device was ITO/2-TNATA/NPB/EML/Alq<sub>3</sub>/LiF/Al and the emissive layer (EML) consisted of undoped and doped layers with GDI-602 as the host and Rubrene (10%) as the dopant.

Based on the measurement of the electro-optical characteristics, the fabricated device showed a pure white emission of CIE(0.33,0.33) at an applied voltage of 9 V. The luminance and efficiency at the white emission were 1050 Cd/m<sup>2</sup> and 0.6 lm/W, respectively.

The fabrication process suggested in this research is simpler than the conventional WOLED process which involves more than two different hosts and/or dopants. In addition, the device proposed in this research has a simple emitting system, so that more stable emission characteristics may be expected against the color changes that occur during long operation, as compared to conventional devices.

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