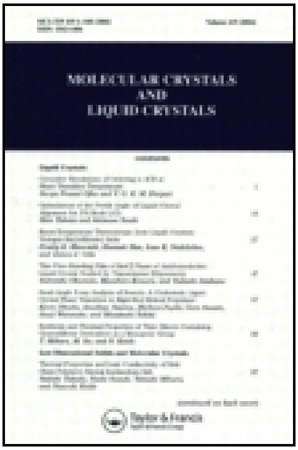

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ORGANIC WHITE LIGHT EMITTING DEVICES WITH AN RGB STACKED MULTILAYER STRUCTURE

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White organic light emitting devices (OLEDs) with an RGB stacked multilayer structure are demonstrated. In RGB staked OLEDs, blue emitting 1,4-bis[2, 2-diphenylvinyl]biphenyl (DPVBi), green emitting quinacridone (QD), and red emitting [2,6-bis[2-[5-(dibutylamino)phenyl]vinyl]-4H-pyran-4-ylidene]propanedinitrile (DADB) were used. Through the optimization of the device structure, the pure white light emission with CIE coordinates of (0.33,0.33) at 20 mA/cm^2 was obtained, at which the color temperature and color rendering index were 5560 K and 79, respectively. Its maximum luminance was 14,000 cd/m^2 at 12.6 V, and the luminance efficiency was 1.34 lm/W at 100 cd/m^2.

Keywords: color rendering index; electroluminescence; white organic light emitting device

1. INTRODUCTION

Next generation flat-panel display based on the organic electroluminescent (EL) materials has attracted many researchers because of several advantages such as processibility, low cost, and large-area application. Full color organic light emitting diode (OLED) displays have been extensively

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investigated since the monochrome OLED display was put on to the market. In order to realize full color display, several approaches have been used. One approach is to pattern red, green and blue emitters using a selective deposition method. Full color can be also obtained by using blue light emitting diodes and color converting medium. Another approach is based on a white light OLED, from which the three primary colors can be obtained by micropatterned color filters. There have been some efforts to obtain white light emission from multi-layer structures in which two- or three emissive layers emit different lights, [1–7] and polymer composites of several different color emitting polymers or dyes [8,9]. Conventionally, white light emission has been realized by combining orange or yellow dye with a blue emitter [1–4]. Although exhibiting higher efficiency, the solution was not suitable for full color displays due to unbalance of red (R), green (G) and blue (B) color. Another approach was to use RGB emitters, simultaneously [5–7]. The balanced emission from RGB peaks provides the white light, which is closer to the natural white light than the previous method. However, the control of three RGB peaks was difficult and the efficiency was low.

For general illumination applications of white OLEDs, the light emission should be bright and have Commission Internationale d'Eclairage (CIE) chromaticity coordinates of (0.33, 0.33). Acceptable illumination sources require also a Color Rendering Index (CRI) of high than 80 and a Color Temperature (CCT) between 3000 K and 6000 K which is equivalent to that of a blackbody source [10]. Currently, there have been efforts to demonstrate high quality white light from OLEDs [2,10].

In this work, we will report on the white EL properties of OLEDs with RGB light emission from an RGB stacked multi-layer structure. The EL spectra of our devices covers a wide range of the visible region, and the CIE coordinates of the emitted light are (0.33,0.33) at 20 mA/cm^2. The CRI of 84 and the CCT of 5560 K were obtained at a CIE chromaticity coordinates of (0.33,0.33).

2. EXPERIMENTAL

As a blue, green and red emissive material, a 1,4-bis[2,2-diphenylvinyl] biphenyl (DPVBi), a quinacridone (QD), and a [2,6-bis[2-[5-(dibutylamino)phenyl]vinyl]-4H-pyran-4-ylidene]propanedinitrile (DADB) were used, respectively. DADB is the newly developed red emitting material by us, which shows good efficiency with pure red emission [11]. The device was prepared by vapor deposition onto an indium tin oxide coated glass substrate with a sheet resistance of 14 Ω/□, and a thickness of 150 nm. The organic layer and the cathode layer were deposited by vacuum vapor deposition at $< 3 \times 10^{-7}$ torr. The device structure included a 20 nm-thick 4,4′,4″-tris(3-methyl-phenylphenylamino) triphenylamine (MTDATA) as a hole injection layer (HIL); a 30 nm-thick N,N′-bis-[1-naphthy(-N,N′diphe nyl-1,1′-biphenyl-4,4′-diamine)] (NPB) as a hole transport layer (HTL); a 5 nm-thick DPVBi; a 15 nm-thick 2.5 wt.% QD doped tris-[8-hydroxyquinoline] aluminum (Alq); a 6 nm-thick 1.5 wt.% DADB doped Alq; a 20 nm-thick Alq as an electron transport layer (ETL), and a cathode. The cathode included a 12-Å-thick LiF and a 1,000-Å-thick Al layer. Figure 1 shows the device structure and the energy band diagram of the RGB stacked OLEDs. The active area of the devices was $2 \times 2\,mm^2$. The ionization potential of all organic materials was determined from the wavelength dependence of photoemission of electrons using Riken Keiki AC-II. The energy gap values were determined from the minimum energy threshold of the electronic absorption spectra from the thin films of the materials. The luminance and color chromaticity of the devices were measured with a Minolta LS110 luminance meter and Minolta CS1000 spectrophotometer. A Keithley 238 electrometer was used to measure the current–voltage characteristics.

3. RESULTS AND DISCUSSION

Monochrome devices containing a 20-nm MTDATA/30 nm NPB/40 nm emissive layer/20 nm Alq/cathode were fabricated. Emissive layer was a

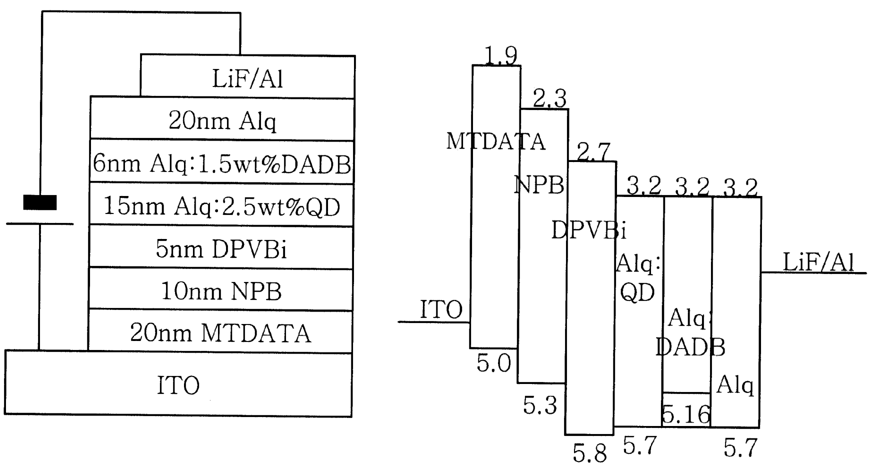

FIGURE 1 The device structure and the energy band diagram of white light emitting OLEDs.

DPVBi, a 2.5 wt.% QD doped Alq and a 1.5 wt.% DADB doped Alq for a blue, green and red light emitting device, respectively. EL peaks of DPVBi, QD and DADB were observed at 460 nm, 547 nm and 638 nm, respectively. As for red emitting device, the doping ratio of the red emitting material, DADB, was optimized due to doping concentration dependence on efficiency and color quality. The doping concentration of 1.5 wt.% was appropriate for acceptable device performance and color quality of a white light emitting OLED. Devices staked with these RGB materials were constructed for white light emission. Through the optimization of the thickness of all organic layers, pure white light emission could be obtained in the structure as shown in Figure 1.

Figure 2 shows the EL spectra and the CIE chromaticity coordinates of RGB stacked OLED with the applied voltages. The EL peaks were observed at 448 nm and 546 nm as that of a DPVBi and a QD doped Alq, respectively. The emission of DADB contributed to the broad tail at long wavelength region. The CIE coordinates are varied from (0.38,0.37) to (0.32,0.33) within a luminance range of 100–1500 cd/m^2 as the applied bias changed from 6 V to 10 V. The device exhibited a pure white color with the CIE coordinates of (0.33,0.33) at 20 mA/cm^2. The blue light emission was enhanced as the applied voltage increased. However, the RGB stacked OLED exhibited the white light emission of the CIE coordinates of which located in the white zone over the all applied voltages. The CCT of the white light at a CIE chromaticity coordinates of (0.33,0.33) was 5560 K, which is close to the daylight of 5500 K.

Figure 3 shows the current (open circle) and the luminance (closed circle) properties of a white OLED as a function of the applied voltage. The turn-on voltage (at 1 cd/m^2) was 4 V in spite of a multiple stacking of emissive layers. The external quantum efficiency was 1.3% and the luminance efficiency was 1.34 lm/W corresponding to 2.6 cd/A at 100 cd/m^2. The maximum luminance was 14,000 cd/m^2 at 12.6 V. The CIE chromaticity coordinates of (0.33,0.33) was not changed for more than 30 hours under the continuous current operating of 15 mA/cm^2 in the air condition.

CRI is a unit of measure that defines how well colors are rendered by different illumination conditions in comparison to daylight. The values of CRI range from 0 to 100, with 100 representing no shift in color with reference light of daylight [12]. White light emitting OLED showed the CRI of 79 at a CIE chromaticity coordinates of (0.33,0.33). That CRI value is high compared with 50 of mercury lamps and 20 of sodium lamps. But, the CRI of over than 80 is required for the illumination light application of general purposes. In the EL spectra of the RGB stacked OLED as shown in Figure 2, a weak EL at the wavelength of 510 nm attributed to the somewhat low CRI value. If the green color luminescence is enhanced, the CRI may increase. Therefore, we fabricated an OLED having an undoped Alq

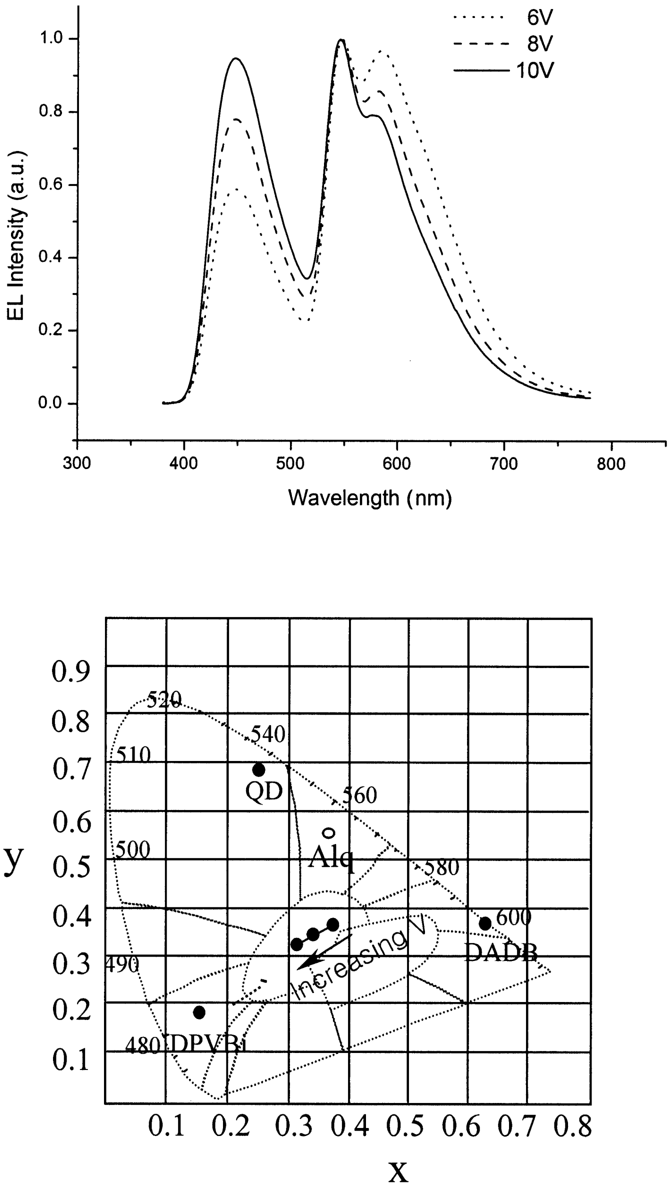

FIGURE 2 The normalized EL spectra and the CIE Chromaticity coordinates of the RGB stacked OLED at various applied voltages.

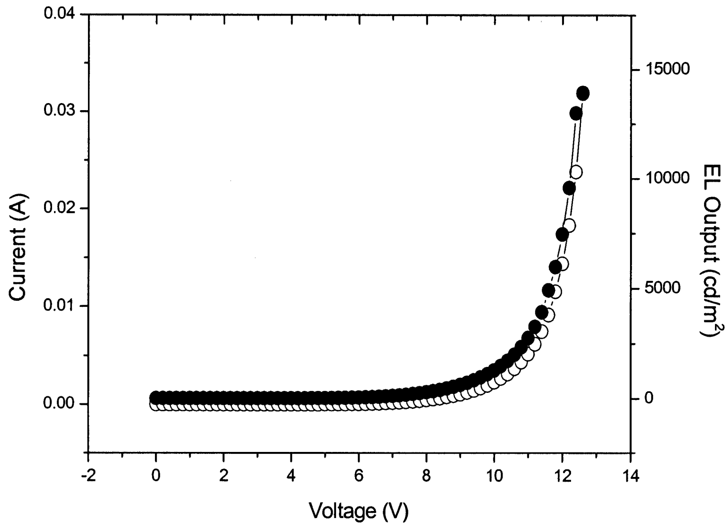

FIGURE 3 Current (open circle) and Luminance (closed circle) vs. applied voltage for white light emitting OLED.

layer as a green emissive layer. Figure 4 shows an EL spectrum of the device at 20 mA/m^2 in which a green emission was enhanced compared with the devices having 1.5 wt.% QD doped Alq. This device showed a CIE

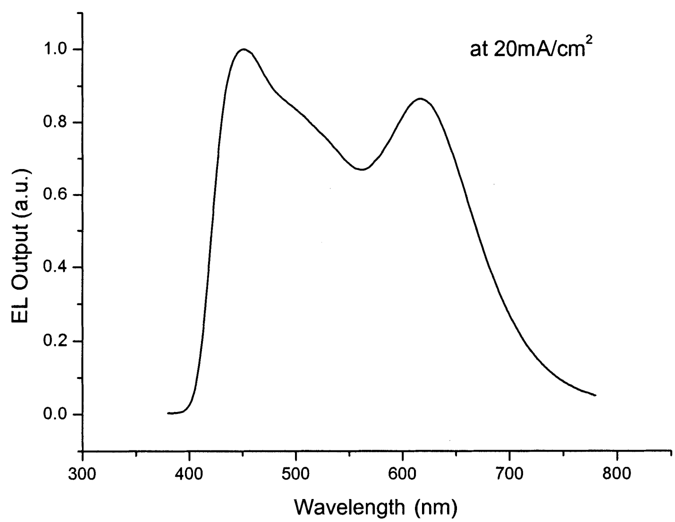

FIGURE 4 The normalized EL spectrum of white light emitting OLED with an undoped Alq layer as a green emissive layer at 20 mA/cm^2.

chromaticity coordinates of (0.33,0.31), a CCT of 5940 K and CRI of 84 at 20 mA/m^2. The enhancement of green region in the EL spectrum improved the rendering property of the white light. For the high quality white light emission, the devices require not only a CIE chromaticity coordinate of (0.33,0.33) but also a full covered EL spectrum of visible region.

4. SUMMARY

We have demonstrated a high quality white light emission from the RGB stacked structure. The full spectrum emission wavelength covered three RGB peaks, and thus was a white light. The reproducibility, color stability and long-term durability of the device are under further investigation.

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