Electro-optical Characterization of OLED Device

Soon-Seok Lee
Dept. of Physics & Advanced Materials Science
Sunmoon University, Asan, Korea

Ki-Seok Kim
R&D Group, NeoView KOLON Co., Ltd., S. Korea
Chungnam, Changcheok, Korea

Sung-Kyoo Lim
Dept. of Electronics Engineering
Dankook University, Cheonan, Korea

ABSTRACT

Small molecule OLED devices were fabricated and the electro-optical characteristics were analyzed. The luminance and color coordinate of the fabricated OLED device were 24,390 cd/m² and (x=0.15, y=0.22), respectively. Current efficiency of 6.8 cd/A and power efficiency of 2.4 lm/W were also obtained under DC operating condition. Transient light intensity was also measured by using Si photodiode.

Keywords *: OLED(organic light emitting diode), luminance, current efficiency, power efficiency, emission spectrum and transient light intensity.*

1. INTRODUCTION

Blue light emission from OLED device[1] was first observed from an anthracene crystal in 1965. OLED displays are now considered as one of the important flat panel displays after green light emission was observed from diamine and Alq_3 OLED device[2][3] in 1987 and 1989. In 1997, monochrome OLED display configured by 256 x 64 pixels was first introduced to the commercial market and in 2002, a full color 5.2 in 1/4 VGA passive-matrix display[4] also was developed. Currently, OLED displays is used as a cell phone display and the OLED market is expected to grow very rapidly.

Recently, organic phosphorescence[5][6] based on the decay of triplet state has been actively studied to increase a luminance and efficiency. Bright white OLED devices[7][8] are also extensively studied to develop full color passive-matrix displays and full color active-matrix displays.

In this paper, the electrical and optical characteristics of OLED devices were measured and analyzed. The luminances depending on voltage and current density in the fabricated OLED were analyzed. The spectrum and the efficiency were also measured. Transient light intensity of OLED as a function of time was measured by using silicon photo diode.

2. MEASUREMENT and DISCUSSIONS

Fig. 1 shows the fabricated OLED device structure. Organic thin films such as 2-TNATA, NPB, ADN and Alq_3 were deposited by thermal evaporation at the deposition rate of 1 Å/sec under 10^{-6} torr. The 2-TNATA, NPB, ADN and Alq_3 were used as HIL(hole injection layer), HTL(hole transport layer), EML(emission layer) and ETL(electron transport layer), respectively. The LiF layer was deposited in the same chamber at the rate of 0.1 Å/sec and used as EIL(electron injection layer). The ITO and the Al metal were used as anode electrode and cathode electrode. The thicknesses of deposited layers were shown in Fig. 1.

Fig. 2 shows the system for measuring the electrical and

* *Corresponding author. E-mail: leess0402@hanmail.net*
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optical characteristics of OLED device. The arbitrary waveform generator generates various voltages for driving the OLED device after amplification. The electrical characteristics of the manufactured OLED device were measured by connecting 50 ohm resistor R_s in series. The current flowing through OLED device is the same as the current flowing through the sense resistor so that the OLED characteristics were easily analyzed by measuring resistor current and using the following equations.

$$v_{OLED}(t) = v_2(t) - v_1(t) \quad (1)$$

$$i_{OLED}(t) = \frac{v_1(t)}{R_s} \quad (2)$$

An instantaneous power consumption in OLED device can be easily calculated by using equation (1) and equation (2). But the instantaneous power described in equation (3) can not be used to calculate power efficiency because it varies with time. Therefore, it is necessary to obtain the average power consumption by integrating the instantaneous power during the period and dividing it by the period. The equation (4) shows the average power consumption in the OLED device.

$$p_{OLED}(t) = v_{OLED}(t)\, i_{OLED}(t) \quad (3)$$

$$P_{OLED} = \frac{1}{T}\int_0^T v_{OLED}(t)\, i_{OLED}(t)\, dt \quad (4)$$

The spectro-radiometer CS-1000A and photo diode shown in Fig. 2 were used to analyze emission spectra and obtain a transient light intensity.

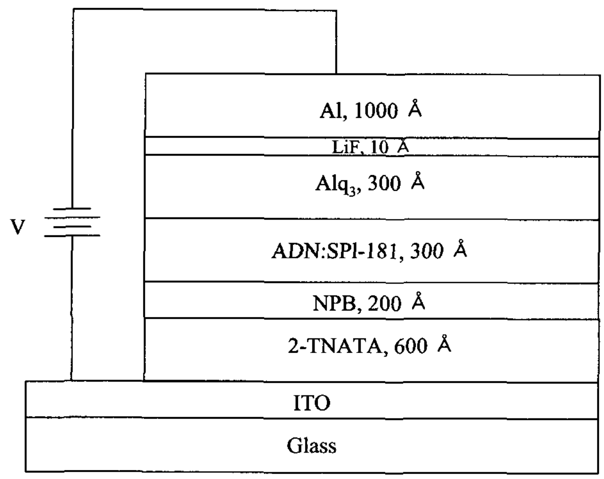


Fig. 1 Cross sectional view of OLED device.

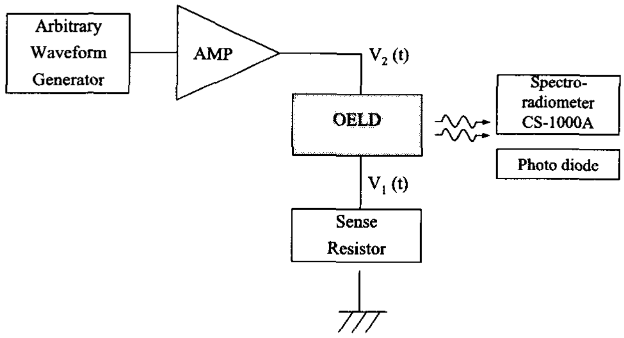
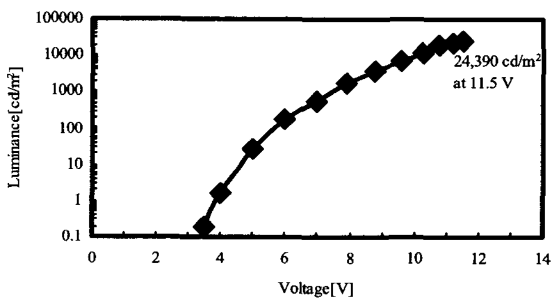


Fig. 2 block diagram of measurement system.

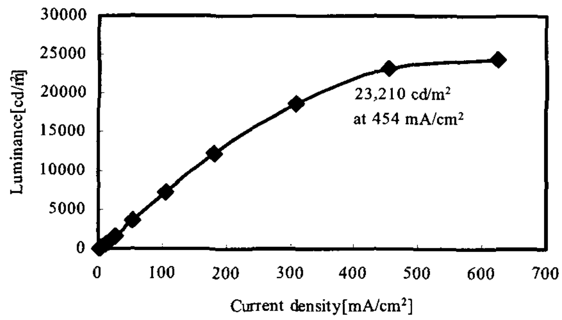
Fig. 3 shows the measured luminance of OLED device according to the applied DC voltage and current. The luminance started to increase rapidly at 3.5 V and measured value of brightness was 24,390 cd/m^2 when the applied voltage was 11.5 V. The luminance also linearly increase as current density increases in the range of under 300 mA/cm^2. The luminance of OLED can be easily controlled by controlling a flowing current in the OLED device and the driving methode of OLED display is more appropriate to be driven by current driving than voltage driving.

Fig. 4 shows an emission spectrum from the manufactured OLED device. The emission peak wavelength and FWHM(full width at the half maximum) were 471 nm and 57 nm, respectively. The CIE coordinate measured was (x=0.15, y=0.22) and the color was blue.

The current efficiency and power efficiency are frequently used to compare the characteristics of the display devices. The current efficiency η_c represents the ratio of luminance to current density as shown in equation (6) and the power efficiency η_e in equation (7) can be easily calculated by dividing luminance by the average power.



(a) Luminance depending on applied voltage.



(b) Luminance depending on current density.

Fig. 3 Luminance as a function of voltage and current density.

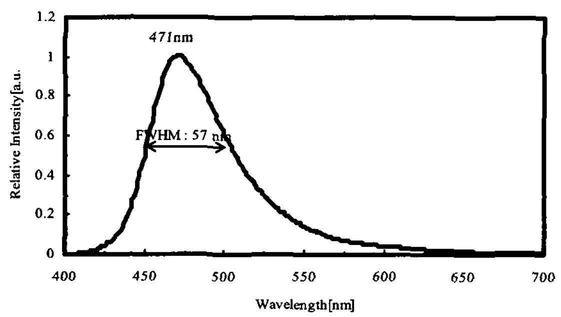
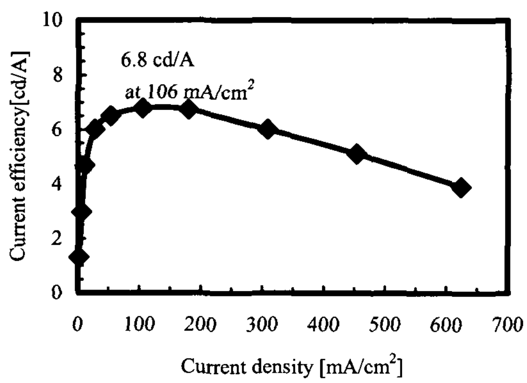


Fig. 4 Emission spectrum of OLED device.

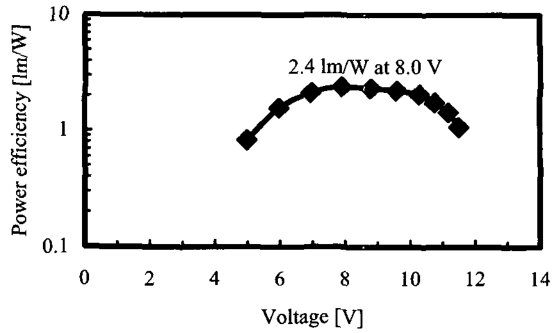
$$\eta_c = \frac{L\,[cd/m^2]}{J\,[A/m^2]} \tag{6}$$

$$\eta_e = \pi \frac{L\,[cd/m^2]}{P_{OLED}\,[W/m^2]} \tag{7}$$

where L, J and P_{OLED} are luminance, current density and average power consumption in OLED device, respectively.



(a) Current efficiency of OLED device.



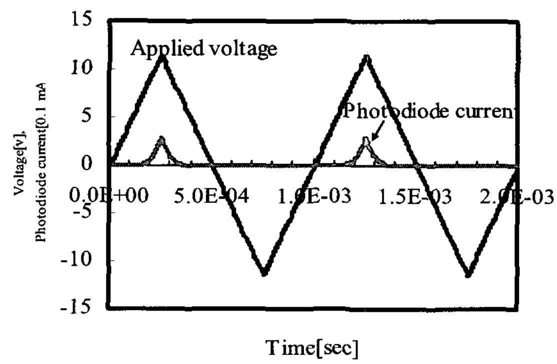
(b) Power efficiency of OLED device.

Fig. 5 Efficiency of OLED device as a function of current density and voltage.

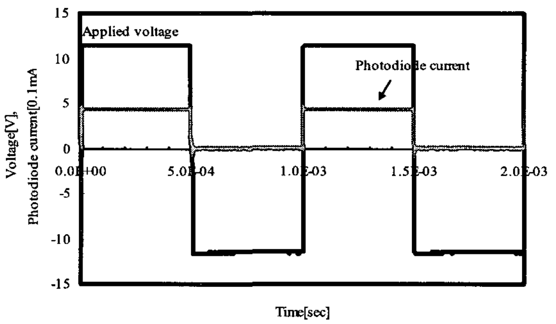
Fig. 5 shows current efficiency and power efficiency of the manufactured OLED device. The current efficiency sharply increased at small current and was saturated as the OLED current density varied from 40 to 300 mA/cm^2. The maximum current efficiency measured was 6.8 cd/A at 106 mA/cm^2.

The power efficiency also varies according to the voltage applied. The maximum efficiency measured was 2.4 lm/W at the applied voltage of 8.0 V. The current efficiency and power efficiency started to decrease after reaching maximum. Many electrons and holes were accumulated in the emitting layer and some of the electron-hole carriers travel to the opposing electrode without recombination, which seems to be the reason for the reduction of the efficiency of the OLED device.

Fig. 6 shows the transient light intensity of the manufactured OLED device as a function of time. The 1 kHz triangular wave voltage and square wave voltage were applied. The voltage amplitude at its peak was 12V. Fig. 6(a) shows the transient light intensity while triangular wave voltage was applied. It increased as voltage increased over 5 V. The transient light intensity increased rapidly and saturated as the square wave voltage was applied. The light intensity decreased dramatically while the voltage was dropping sharply.

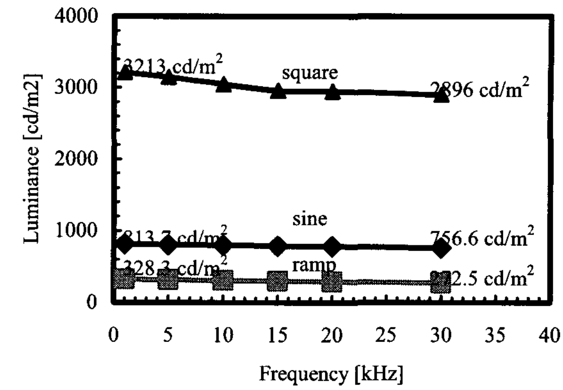


(a) Transient light intensity under triangular voltage.



(b) Transient light intensity under square voltage.

Fig. 6 Transient light intensity as a function of time and voltage forms.

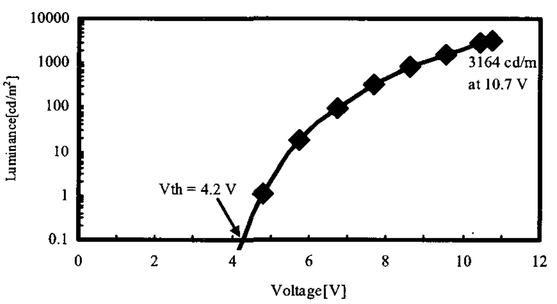


(b) Luminance depending on frequency.

Fig. 7 Luminance depending on voltage waveform and fequency.

But there was no light emission during the negative voltage application. The light emission of OLED device against applied voltage was very similar to OLED current against applied voltage.

Fig. 7 shows the luminance and power efficiency as square, sinusoidal or triangular voltage were applied. The luminance under the application of square wave voltage was different from the luminance under the application of DC voltage as shown in Fig. 3(a). The luminance started to increase rapidly at 4.2 V and measured value of brightness was 3,164 cd/m^2 when the applied voltage was 10.7 V. The luminance measured under various voltage waveforms was lower than the luminance measured under the application of DC voltage, which seems to be the reason for the non-emission during negative voltage. It was also found that the threshold voltage(V_{th}) increased from 3.5 V to 4.2 V as the applied voltage changed from DC to the voltage with different waveforms. Fig. 7(b) show luminance as a function of frequency at the applied voltage of 10.7 V. The luminance under square wave voltage was the highest of the three voltage waveforms applied. The luminance under the application of triangular voltage was the lowest, which is due to the difference of duration of peak voltage applied. The duration of maximum voltage of square voltage is longest out of the three voltage waveforms applied. Fig. 7(b) also shows that the luminance slowly decreases as the frequency increases, which is related with the capacitor of OLED device[9]. It takes time to charge the capacitor of OLED device.



(a) Luminance depending on amplitude of square wave voltage.

3. CONCLUSION

Small molecule OLED devices were fabricated by thermal evaporation at the deposition rate of 1 Å/sec under 10^{-6} torr. The electro-optical characteristics of the OLEDs were analyzed.

The luminance and color coordinate of the fabricated OLED device were 24,390 cd/m^2 and (x=0.15, y=0.22) at the applied voltage of 11.5 V_{DC}. The emission color observed was blue. The efficiency of OLED devices increased, and saturated and decreased as applied voltage increased. The maximum current efficiency of 6.8 cd/A and the maximum power efficiency of 2.4 lm/W were also obtained.

Transient light intensity was also measured by using Si photodiode. It increased as voltage increased over 5 V. But light emission was not observed as the voltage went negative. The light emission characteristics against applied voltage was very similar to the current characteristics against voltage applied to OLED.

The luminance of OLED under square wave voltage was different from the luminance under DC voltage due to the non-emission of light during the negative voltage cycle and the luminance slowly decreased with frequency increased.

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Soon-Seok Lee

He received the B.S, M.S and Ph D in electronics engineering from Dankook University, Korea in 1987, 1989 and 1999 respectively. He is currently a visiting professor in Dep. of physics & advanced materials science at Sunmoon University. His main research interests include flat panel display and its characterization.

Sung-Kyoo Lim

He recei ved the B.S, M.S in electronics engineering from Seoul National University, Korea in 1975 and 1977 respectively and Ph D degree in computer and electrical engineering in Oregon State University in 1993. He is currently a professor in Dep. of electronics engineering at Dankook University. His main research interests include flat panel display, BLU and inverter.

Ki-Seok Kim

He received the BS, MS in chemistry from Korea university, Korea in 1990, 1992 respectively. He is currently a Chief of R&D group in NEOVIEWKOLON. He is in charge of development of OLED device and OLED emitting material.