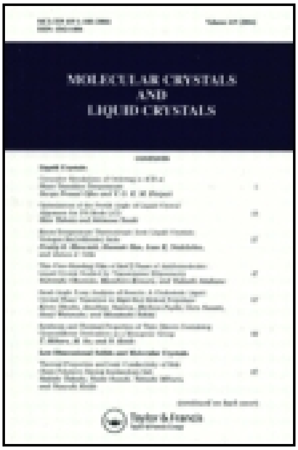

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Ji Geun Jang [a] , Se Jin Shin [a] , Sung Kyoo Lim [a] , Ho Jung Chang [a] , Sang Ouk Ryu [a] , Myoung Seon Gong [b] & Jun Yeob Lee [c]

[a] Department of Electronic Engineering, Dankook University, Chungnam, Korea

[b] Department of Chemistry, Dankook University, Chungnam, Korea

[c] Department of Polymer Science and Engineering, Dankook University, Kyeonggi, Korea

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Effect of Plasma Treatment of ITO Electrode on the Characteristics of Green OLEDs with Alq_3-C545T Emissive Layer

Ji Geun Jang[1], Se Jin Shin[1], Sung Kyoo Lim[1], Ho Jung Chang[1], Sang Ouk Ryu[1], Myoung Seon Gong[2], and Jun Yeob Lee[3]

[1]Department of Electronic Engineering, Dankook University, Chungnam, Korea
[2]Department of Chemistry, Dankook University, Chungnam, Korea
[3]Department of Polymer Science and Engineering, Dankook University, Kyeonggi, Korea

The influence of the plasma treatment of the ITO (Indium Tin Oxide)/glass substrate was investigated in the fabrication of green OLEDs (Organic Light Emitting Devices) using the Alq_3-C545T fluorescent system. Various plasma powers of 100 W, 150 W, and 200 W were used under the fixed conditions of an Ar/O_2 gas mixing ratio of 0.5 and pressure of 1 m Torr during the plasma treatment. The threshold times required for the inter-insulator width between the subpixel regions to be reduced to 80% of their original value were found to be 4, 3, and 2 minutes at plasma powers of 100 W, 150 W, and 200 W, respectively. The plasma treatment durations at each power were varied from 1 minute up to the threshold time with intervals of one minute.

The basic structure of the fabricated devices was 2TNATA/NPB/Alq_3-C545T/Alq_3/LiF/Al and the best emission characteristics were obtained in the case of the plasma treatment at 150 W for 2 minutes. The luminance and power efficiency of the device treated with the optimum plasma condition were 20000 cd/m^2 and 16 lm/W at 10 V, respectively. The peak wavelength and the CIE coordinates were found to be 522 nm and (0.32, 0.63), respectively.

Keywords: Alq_3-C545T; CIE coordinate; luminance; OLED; plasma treatment; power efficiency

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Addres correspondence to Prof. Ji Geun Jang, Department of Electronics Engineering, Dankook University, San 29, Anseo-dong, Cheonan, Chungnam 0330-714, Korea (ROK). E-mail: semicgk@dankook.ac.kr

INTRODUCTION

Organic light emitting diodes (OLEDs) generate a specific wavelength of light equivalent to the energy band gap of the emission material. The mechanism of light emission in OLEDs is known to involve the injection of electrons and holes and their transport from the cathode and anode into the emission layer, followed by the generation and recombination of excitons in the emission layer [1–3]. The carrier injection and transport in multi-layered OLEDs are strongly influenced by the interfacial states between the layers, as well as by the material making up each layer [4,5]. Therefore, it is important to choose the appropriate material for the various layers and obtain a good interface between them, especially between the ITO and first organic layers, in order to develop high quality OLEDs. The surface smoothness and adhesion between the layers are also important for obtaining high quality OLEDs. Organic materials can deteriorate quickly upon exposure to oxygen and humidity [6,7], so that the use of an in-situ process under high vacuum conditions is essential for the fabrication of OLEDs.

The OLED fabrication process consists of cell partitioning and plasma treatment, the evaporation of organic and metal thin films, and encapsulation. The plasma treatment removes the impurities on the substrate before organic layer evaporation and reduces the surface roughness of the ITO electrode. Moreover, the plasma treatment increases the work function of the ITO electrode and lowers the energy barrier for the injection of holes from the anode [8,9]. Therefore, the plasma treatment of the ITO electrode before organic material evaporation is one of the core technologies for the fabrication of OLEDs.

In this study, the optimum plasma condition in the fabrication of high quality green OLEDs was examined by investigating the ITO surface roughness and the electro-optical characteristics of ITO/2-TNATA/NPB/Alq_3-C545T/Alq_3/LiF/Al devices with different plasma treatments.

EXPERIMENTAL PROCEDURE

A partitioned substrate with inter-insulator and cathode rib between the subpixel regions on the ITO/glass was prepared to investigate the effect of the plasma threshold time at various powers, as shown in Figure 1. Figure 1 shows the cross sectional view of the partitioned substrate before the plasma treatment. During the plasma treatment, the mixing gas ratio and the internal pressure were fixed at $Ar/O_2 = 1/2$ and 1 m Torr, respectively. If we assume the plasma

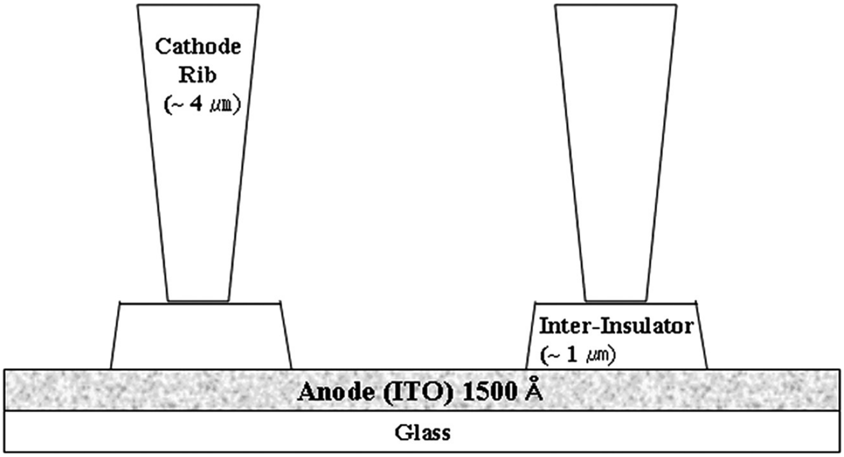


FIGURE 1 Cross sectional view of the partitioned substrate before plasma treatment.

threshold time to be the time taken for the inter-insulator width to be reduced to 80 % of its original value, then its values were 4, 3, and 2 minutes at plasma powers of 100 W, 200 W, and 300 W, respectively. Figure 2 shows the microphotographs of the partitioned regions (a) before plasma treatment and (b) after plasma threshold treatment. As shown in Figure 2, the inter-insulators were reduced to 80% (28 μm) of their original width (35 μm) after the plasma treatment for the threshold time at each power. Figure 3 shows the root mean square (rms) values of the ITO surface roughness according to the duration of the plasma treatment. The surface roughness showed a minimum value at one minute before the threshold time when the inter-insulator started to shrink. Figure 4 shows the atomic force microscope (AFM) images of the ITO surface before the plasma treatment and the ITO surfaces which were plasma-treated for 3, 2, and 1 minutes at 100 W, 150 W, and 200 W, respectively. The rms values of the ITO surface roughness were 0.90 nm, 0.93 nm, and 0.94 nm when using plasma powers of 100 W for 3 minutes, 150 W for 2 minutes, and 200 W for 1 minute, respectively. These values correspond to the minimum rms values at one minute before the threshold time at each power, indicating that better surface roughness is obtained at a lower power.

In the fabrication of the OLEDs, the ITO layer on the glass was firstly stripe-patterned to form the anode by photolithography technology. Then, the substrate was cleaned and loaded into the plasma chamber.

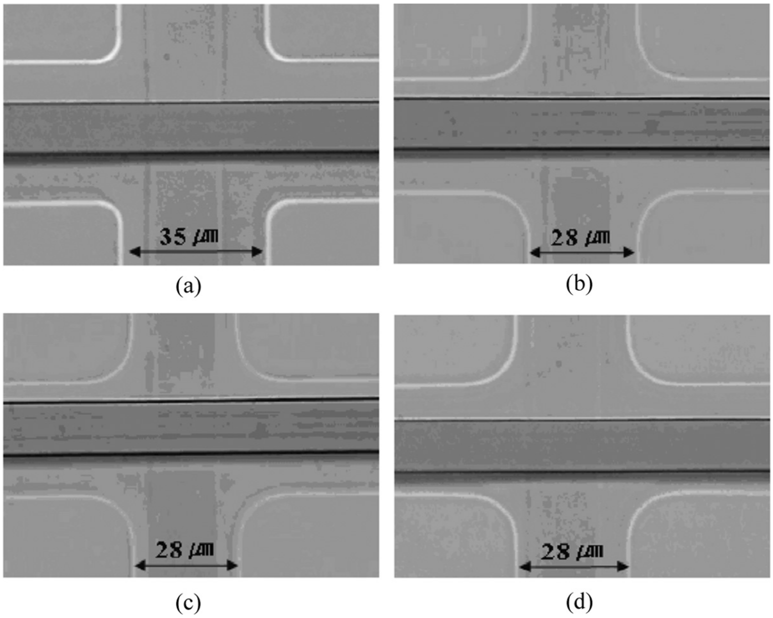


FIGURE 2 Microphotographs of the partitioned regions before plasma treatment and after plasma threshold treatment: (a) non-treatment, (b) 100 W for 4 min, (c) 150 W for 3 min, and (d) 200 W for 2 min.

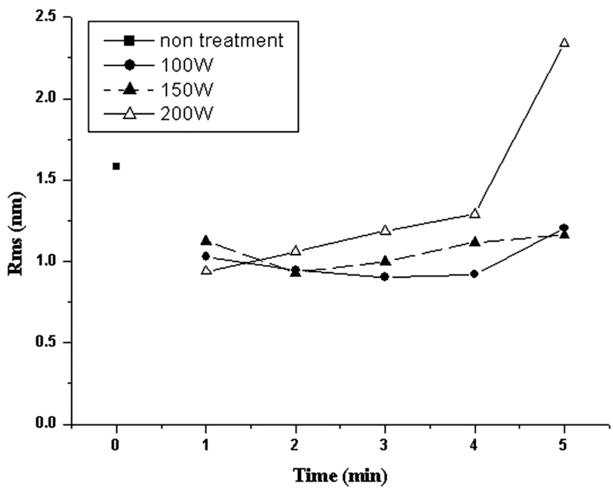


FIGURE 3 Root mean square values of ITO surface roughness.

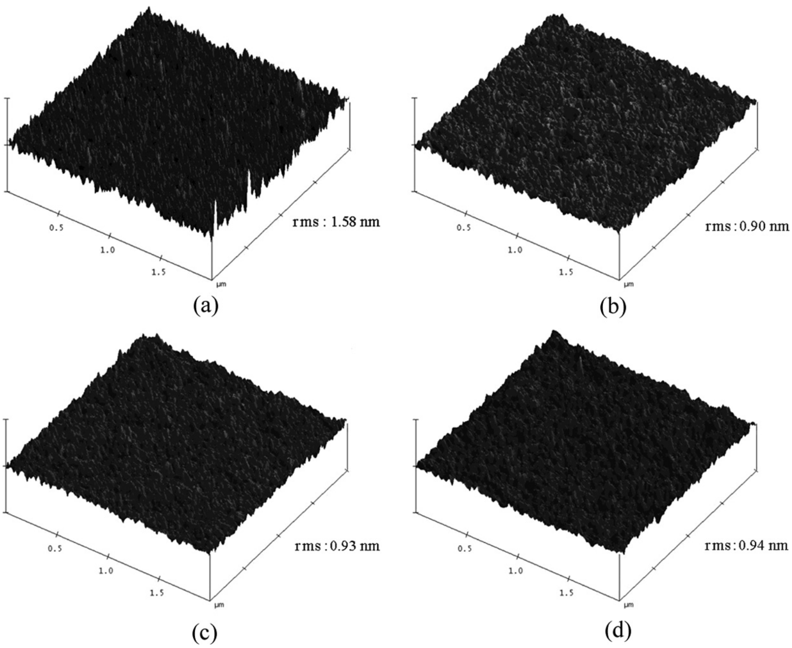


FIGURE 4 AFM images of ITO surface according to the plasma treatment: (a) non-treatment, (b) for 3 minutes at 100 W, (c) for 2 minutes at 150 W, and (d) for 1 minute at 200 W.

The plasma treatment times were chosen so as to use various durations ranging from 1 minute up to the threshold time at the plasma powers of 100 W, 150 W, and 200 W. The plasma-treated substrate was moved into the high vacuum ($\leq 5 \times 10^{-8}$ Torr) organic chamber and the 600Å-thick hole injection layer (HIL) and 250Å-thick hole transport layer were then formed using 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], respectively. The 200Å-thick emissive layer was formed using Alq_3 (host) [tris(8-hydroxy-quinolinato)aluminium] and C545T(dopant) [10-(2-benzothiazolyl)-1,1,7,7-tetramethyl-2,3,6,7-tetrahydro-1H,5H,11H-[1]/benzopyrano[6,7,8-ij]-quinolizin-11-one] at an evaporation ratio of 100:1. Then, the electron transport layer (ETL) was formed with 300Å-thick Alq_3. Finally, the sample was moved to the metal chamber and the 10Å-thick LiF and 1800Å-thick Al as a cathode were sequentially formed. Figure 5 shows the deposited film layers and layout of the fabricated device. In this figure, 4 OLED devices are integrated on one substrate and the light emission area of the unit device is 2 mm $\times$ 2 mm.

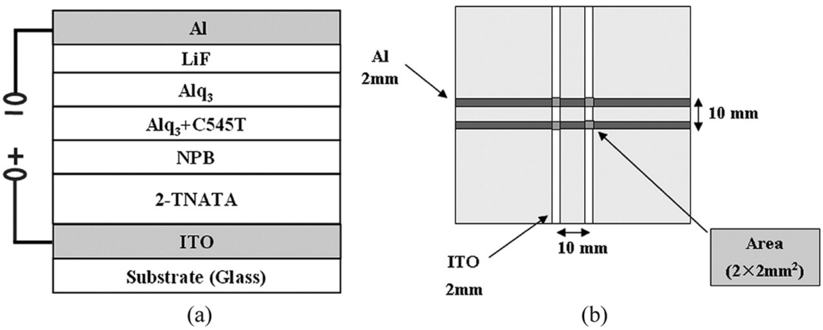


FIGURE 5 Device structure: (a) stacked film layers and (b) layout on the substrate.

RESULTS AND DISCUSSION

The current-voltage characteristics of the fabricated OLED device were measured by an HP4145B semiconductor parameter analyzer and the luminance, emission spectra, and CIE coordinates were analyzed by a CS-1000 spectrometer.

Figure 6 shows the luminance-voltage characteristics of the fabricated OLED devices. The threshold voltage based on a luminance of 10 cd/m^2 was about 4 V. The maximum luminance was observed at an input voltage of 10~12 V. The plasma-treated devices showed better luminances than those of the devices without plasma treatment. The maximum luminance was obtained from the device plasma-treated for 2 minutes at 150 W. The luminance for the device without plasma treatment was 4000 cd/m^2 at 10 V, while that for the device with plasma treatment for 2 minutes at 150 W was about 20 000 cd/m^2 at the same voltage.

The luminance efficiency (η) can be calculated by the equation of $\eta = (\pi L)/(VJ)$ if the current density-voltage and luminance-voltage relationships are known, where L (cd/m^2), V(V), and J(A/m^2) are the luminance intensity, applied voltage, and current density, respectively.

Figure 7 shows the power efficiency-voltage curves calculated at the various applied voltages. The power efficiency stayed almost unchanged in the range of 6~10 V and tended to decrease when the applied voltage was further increased. This might be due to the luminance saturation and the increase of the injected current at high voltage. The efficiencies of the plasma-treated devices at the power/time of 100 W/3min, 150 W/2min, and 200 W/1min were 3.4 lm/W, 16

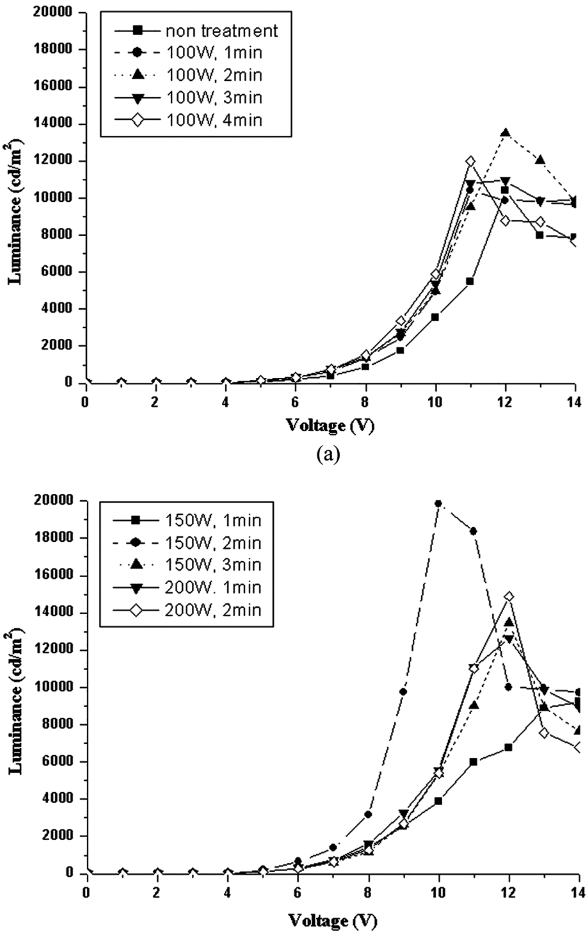
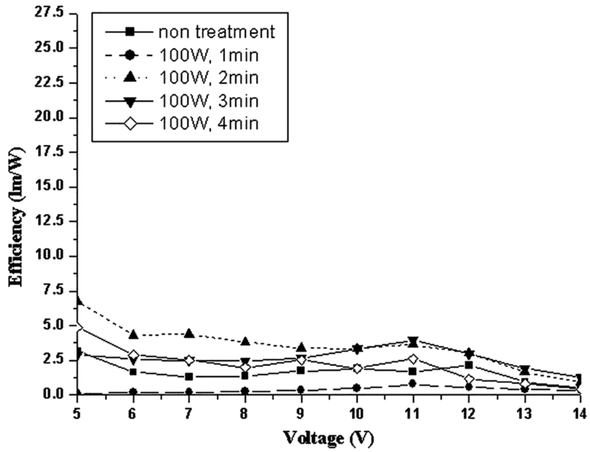


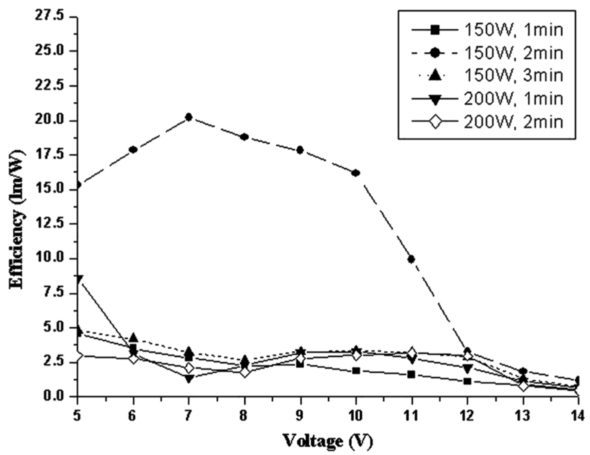
FIGURE 6 Luminance-voltage characteristics of OLED devices under various plasma treatment conditions.

lm/W, and 3.3 lm/W at 10 V, respectively. The device subjected to plasma treatment for 2 minutes at 150 W showed the highest luminance of all the devices.

Figure 8 shows the emission spectra and color coordinates of the device plasma-treated for 2 minutes at 150 W. The peak wavelength and full width at half maximum (FWHM) in the emission spectra of



(a)



(b)

FIGURE 7 Power efficiency-voltage characteristics of OLEDs under different plasma treatment conditions.

Figure 8(a) were 522 nm and 505~560 nm, respectively. The CIE coordinates were (0.32, 0.63), showing a color purity of more than 90% in Figure 8(b).

The superior emission characteristics of the device subjected to plasma treatment for 2 minutes at 150 W compared to those of the other samples result from the optimum treatment in the plasma process.

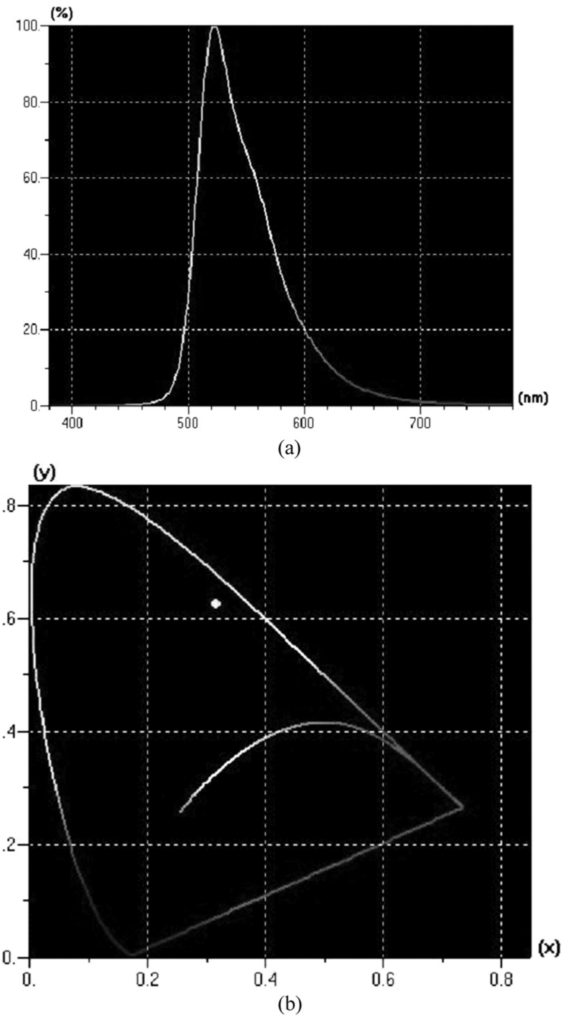


FIGURE 8 (a) Emission spectra and (b) CIE color coordinates at an applied voltage of 10 V for the green OLED subjected to plasma treatment for 2 min at 150 W.

CONCLUSIONS

The green OLED devices based on the Alq_3-C545T fluorescent system were fabricated with various conditions of power and time in the plasma treatment under the condition of an Ar/O_2 gas mixing ratio of 0.5 and pressure of 1 m Torr. The surface roughness of the ITO electrode showed a minimum value at one minute before the threshold time at each power.

The best emission characteristics were observed from the OLED devices treated with the plasma for 2 minutes at 150 W. The luminance and efficiency of the OLED treated with the plasma for 2 minutes at 150 W were 20000 cd/m^2 and 16 lm/W, respectively. The peak wavelength and CIE coordinates were 522 nm and CIE (0.32, 0.63), respectively.

Judging from the surface roughness of ITO and the emission characteristics of the fabricated devices, the optimum power and time in the plasma treatment on the ITO/glass before organic material deposition were thought to be 150 W and 2 min, respectively, under an Ar/O_2 gas mixing ratio of 0.5 and pressure of 1 m Torr.

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