Post-annealing effect of copper phthalocyanine on enhancing the performance of green organic light-emitting diode

Sun-Zen Chen[++], Jwo-Huei Jou[*], Po-Hsuan Chiang[*], Fu-Syong Tang[+], and Chin-Yeh Chang[*]

[++] Center for Nanotechology, Materials Science, and Microsystems, National Tsing Hua University, Hsin-Chu, Taiwan 30013, Republic of China

Tel: 886-3-5742285

Fax: 886-3-5742296

E-mail: szchen@mx.nthu.edu.tw

[*] Department of Materials Science and Engineering, National Tsing Hua University, Hsin-Chu, Taiwan 30013, Republic of China

[+] AU Optronics Corporation, No. 1, Li-Hsin Rd. 2, Hsin-chu Science Park, Hsin-chu, Taiwan 30078, Republic of China

Abstract

Post-annealing copper phthalocyanine (CuPc) can effectively improve the efficiency of a green organic light-emitting diode, consisting of indium tin oxide/CuPc/N,N'-bis-(1-naphthyl)-N,N'-diphenyl-1,10-biphenyl-4-4'-diamine/tris-8-hydroxy-quinoline aluminum/lithium fluoride /aluminum. By annealing the device at 120℃ for 1 hr, the power efficiency was increased from 1.7 to 2.0 lm/W, with a required driving voltage dropping from 4.7 to 4.2 V. The improvement may be correlated to the smoothening of the CuPc surface upon annealing.

Keywords: OLED, copper phthalocyanine (CuPc), post-annealing effect.

Objective and Background

Since Tang and VanSlyke developed the first high efficiency multilayer organic light-emitting device (OLED),[1] OLEDs have attracted wide spread interests due to their potential applications in lighting, display, and even decoration. It is important to improve OLED characteristics in order to fully realize its commercialization. Therefore, many researchers have been devoted to improve device structures and to understand their operations.

One way to improve the performance of OLEDs is to introduce a buffer layer between anode and hole-transporting layer (HTL) as a hole-injection layer (HIL).[2-6] Among them, copper phthalocyanine (CuPc) is adopted as the HIL to enhance the performance of OLEDs. Modification by heat treatment is another effective method to improve the characteristics of OLEDs.[7-9] In the studies of Sun[7] and Chen,[8] heat treatment was conducted on HTL or other selected layers, but not on HIL. Fenenko[9] observed deterioration of the OLED's characteristics for post-annealing the CuPc layer at 250℃.

Although there are many studies focusing on the characteristics of OLEDs by modifying the structures or changing constitution materials, there are little lectures concerning on the post-annealing effect on HIL. Furthermore, there is no study on post-annealing effect of HIL at various temperatures. In this work, we study the post-annealing effect of CuPc, which is a HIL, at temperatures ranging from room temperature (R. T.) to 160℃.

Results

Figure 1 shows the layer structure of the studied green OLED, consisting of indium tin oxide/CuPc/N,N'-bis-(1-naphthyl)-N,N'-diphenyl-1,10-biphenyl-4-4'-diamine/tris-8-hydroxy-quinoline aluminum/lithium fluoride/aluminum. Thermal annealing of CuPc is performed at $5.0*10^{-5}$ torr at R. T., 120℃ or 160℃ for 1 hr. A Keithley 238 high current source meter was used to measure the current–voltage characteristics. The morphologies of CuPc with or without post-annealing were observed by atomic force microscopy (AFM) (Nanoscope III, Digital Instruments, USA). The inset of figure 1 shows the molecular structure of CuPc.

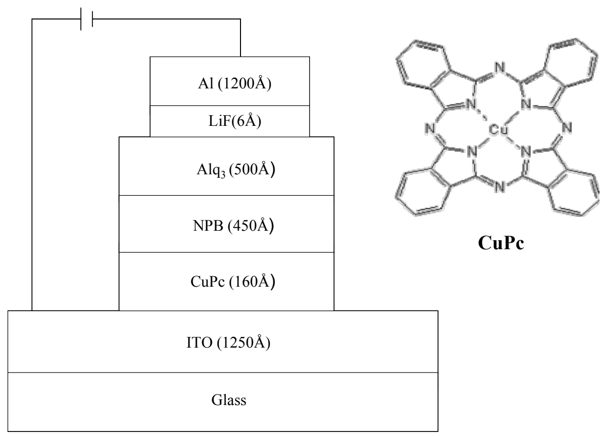

Figure 1. Layer structure of the studied green OLED and molecular structure of CuPc.

Figure 2 shows the luminance-voltage characteristics of the green OLEDs. Some measured values are listed in Table I. As shown in Figure 2, after post-annealing at 120℃ for 1hr, the green OLED shows higher luminance than that without any heat treatment. Further treatment at higher temperature, such as 160℃ for 1hr, the luminance of the green OLED becomes lower. The maximum luminance value of the device post-annealing at 120℃ for 1hr is 17,850 cd/m^2 which is the highest as compared to those without post-annealing (15,100 cd/m^2) and post-annealing at 160 ℃ (15,730 cd/m^2). The maximum power efficiency of the studied OLED increases from 1.7 to 2.0 lm/W as annealing temperature is raised from R. T. to 120℃. It decreases to 1.5 lm/W for annealing at 160℃ for 1hr. Post-annealing at 120℃ for 1hr also results in a lowest driving voltage 3.5 V as comparing to those without any treatment (3.8 V) and after 160℃ treatment (4.2 V).

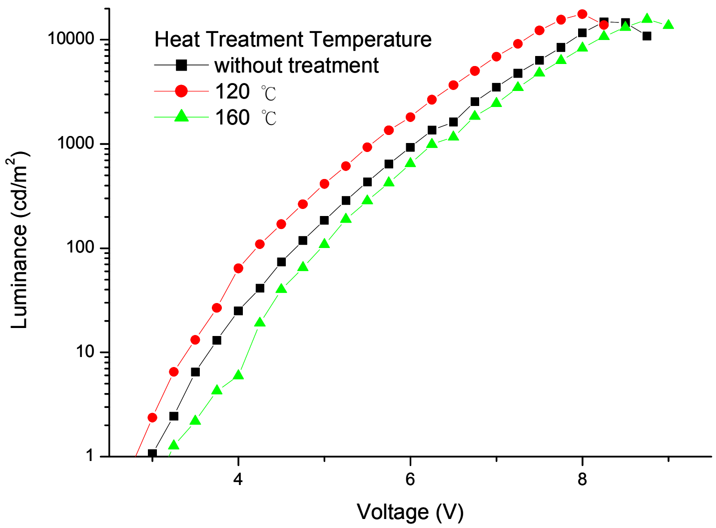

Figure 2. Post-annealing effect of CuPc on the luminance-voltage characteristics.

Table I. Post-annealing effect of CuPc on the characteristics of green OLEDs.

Heat treatment temperature of CuPc	Average Roughness (nm)	Maximum Height of Spike (nm)	Driving Voltage (V) at 10cd/m^2	Maximum Luminance (cd/m^2)	Maximum Power Efficiency (lm/W)
Without Treatment	2.1	72.5	3.8	15,100	1.66
120℃	2.2	70.7	3.5	17,850	1.95
160℃	2.6	98.4	4.2	15,730	1.47

Clean Technology 2008, www.ct-si.org, ISBN 978-1-4200-8502-0

In order to investigate why superior characteristics have occurred for the device post-annealed at 120℃ for 1hr, we use AFM to measure the CuPc surface topologies at various annealing temperatures. Figure 3 shows the results of AFM. The scanning area is 10μm*10μm. The statistic value of the roughness derived from Figure 3 is also listed in Table I. In Figure 3(a), there are many spikes existing on the CuPc surface, meaning the morphology is rather rough as deposited. As shown in Figure 3(b), the number of spikes decreases after post-annealing at 120℃ for 1hr. The spikes increase in number and size after post-annealing at 160℃ for 1hr, as observed in Figure 3(c). Maximum height of spike appears for the OLED post-annealed at 160℃, which is 98.4 nm. The lowest one is that annealed at 120℃ (70.7 nm), and the middle one is that without any treatment (72.5 nm). The average roughness of post-annealing at 160℃ OLED also has highest values of 2.6 nm, the values of annealed at 120℃ and without treatment are almost the same (2.1~2.2 nm).

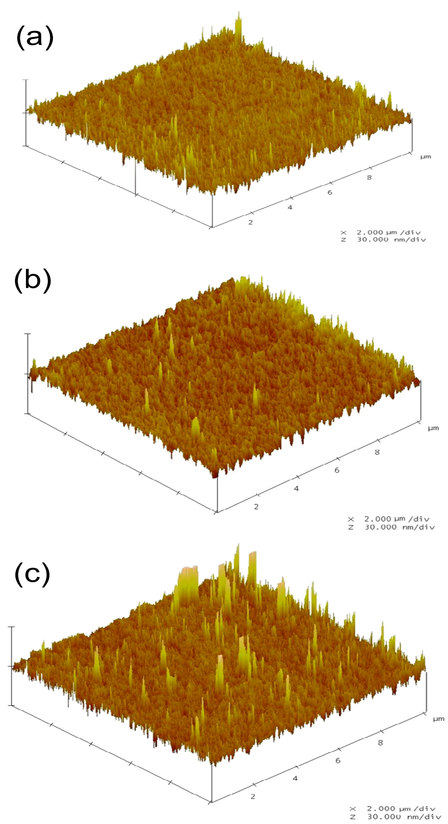

Figure 3. AFM images of the CuPc surfaces: (a) without heat treatment, (b) post-annealing at 120℃ for 1hr, (C) post-annealing at 160℃ for 1hr.

Combining the results shown in Figure 2 and Figure 3, it is easy to find the surface morphology of CuPc layer has a great effect on characteristics of OLEDs. The lower roughness the CuPc layer shows, the better characteristics the OLED behaves.

Impact

In this work, we find the characteristics of OLEDs can be improved by proper post-annealing of HIL. For CuPc, the annealing temperature is 120℃ and annealing time 1hr. Previous investigations usually use new materials or new structures to improve the characteristics of OLEDs. Few studies discuss the effects of heat treatments on OLEDs. There is no literature revealing that it is an effective way to improve the performance of OLEDs by post-annealing the hole-injection layer. We had proved in this paper that properly post-annealing the HIL would enhance the device performance.

Reference

[1] C. W. Tang, S. A. VanSlyke, *Appl. Phys. Lett.*, **1987**, 51, 913.

[2] H. Vestweber, *Synth. Met.*, **1997**, 91, 181.

[3] H. Aziz, Z. D. Popovic, N. X. Hu, A. M. Hor, G. Xu, *Science*, **1999**, 283, 1900.

[4] S. F. Chen, C. W. Wang, *Appl. Phys. Lett.*, **2004**, 85, 765.

[5] Wallace C. H. Choy, Y. J. Liang, K. N. Hui, H. H. Fong, *Proc. of SPIE*, **2005**, 5937, 59371.

[6] Y. H. Lee, W. J. Kim, T. Y. Kim, J. Jung, J. Y. Lee, H. D. Park, T. W. Kim, J. W. Hong, *Curr. Appl. Phys.*, **2007**, 7, 409.

[7] M. C. Sun, J. H. Jou, W. K. Weng, Y. S. Huang, *Thin Solid Films*, **2005**, 491, 260.

[8] B. J. Chen, X. W. Sun, T. K. S. Wong, X. Hu, A. Uddin, *Appl. Phys. Lett.*, **2005**, 87, 063505.

[9] L. Fenenko, C. Adachi, *Thin Solid Films*, **2007**, 515, 4812.