Efficiency enhancement of Organic Light Emitting Diodes by the Aluminum Oxynitride Buffer Layer

Hyungjun Park[1] , Kyungsoo Jang[1], Sungwook Jung[1], Sunghyun Hwang[1],Jeoungin Lee[1], Kwangsoo Lee[1], Keunhee ParK[2], Eunkyoung Nam[2], Donggeun Jung[2], Junsin Yi[1]*

[1]School of information and communication engineering, Sungkyunkwan University, Suwon 440-746, Korea

TEL:82-31-290-7174 , E-mail : yi@yurim.skku.ac.kr

[2]Dept. of physics, Institute of Basic Science, and Brain 21 Physics Research Division, Sungkyunkwan University, Suwon 440-746, Korea

Keywords : Organic light emitting diodes, AlON, Barrier height, Buffer layer

Abstract

In organic light emitting diodes (OLEDs), the electrons and holes need to be injected efficiently to obtain the best device performance. This means that a small injection barrier height at the ITO/organic interface is required. In this study, the surface of the ITO anode was treated with an Aluminum oxynitride (AlON).

1. Introduction

Small molecules are widely used in organic light emitting diodes for flat panel displays and large area illuminating devices. The motivation for using these materials is derived from the report of Tang *et al.* concerning their work on organic materials based on tris-(8-hydroxyquinoline) aluminum (Alq_3) for use in multilayer electroluminescent devices [1]. The characteristics of OLEDs are affected not just by the properties of their constituent organic layers, but also by the electrodes and their interfaces with the charge-transport layers [2]. Recent research efforts have focused on improving the injection and emission efficiency and reliability, and understanding the device physics [3-5]. Therefore, it is generally realized that the optimization of the charge injection and transport properties is of critical importance for obtaining bright and efficient OLEDs. In other words, it is important to balance the numbers of holes and electrons injected into the emitter layer to achieve high recombination efficiencies. The anode is typically a high-work-function material suitably conditioned for hole injection into the organic hole transport layer. Indium tin oxide (ITO) has frequently been used as it offers transparency as well as reasonable sheet resistance. The injection efficiency largely depends on the work function of the electrode [6,7]. Various methods have been tried to enhance the device performance. Some inorganic materials have been adopted as hole injection buffer layers inserted between the ITO anode and the hole transport layer (HTL) [8]. The insertion of a buffer layer can improve the OLEDs performance from several points of view, such as reducing the operating voltage, and enhancing the current injection and luminance efficiency [9]. By inserting an insulating hole-injection buffer material between the ITO anode and HTL, the injection of holes from the ITO layer can be controlled and, hence, the number of electrons and holes in the emitting layer can be matched, so as to increase the device efficiency. In this work, AlON has been used to act as an anode modification layer to replace those conventionally used organic buffer layer materials.

2. Experimental

ITO (150nm)-coated glass with a sheet resistance of 20 Ω/□ was used as the anode for the fabrication of the OLED. In this process, the ITO glass was cleaned sequentially in ultrasonic baths consisting of trichloroethylene, acetone, and methanol, then sonicated in deionized water and finally blown dry with N_2 gas. For the AlON treatment, samples were prepared by RF magnetron sputtering system with a magnet assembly and a power of 100 W. Low RF power of 100W was used in order to minimize the substrate heating and the anode damage due to electron and ion bombardment. As the target, AlN with 99.95% purity and a diameter of 4 in. was used. The sputtering gas was 99.999 % pure argon (Ar) and oxygen (O_2) mixture. AlON films of various thicknesses were deposited. After the surface treatments, N,N'-diphenyl-N,N'-bis(3-methylphenyl)-1,1'-diphenyl-4,4'-diamine (TPD, 32 nm), tris-(8-hydroxyquinoline) aluminum (Alq_3, 48 nm), lithium fluoride (LiF, 0.5 nm), and Al (90 nm) were sequentially deposited as the hole transport layer (HTL), the emitting material layer (EML), the cathode interfacial layer, and the cathode, respectively. The device configuration of ITO/ AlON/ TPD/ Alq_3/ LiF/Al is shown in Fig. 1. A Keithley 2400 electrometer was used as the voltage source and current measurement equipment for plotting the current density-voltage (*J-V*) characteristics.

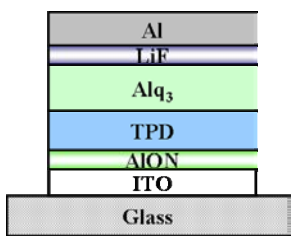
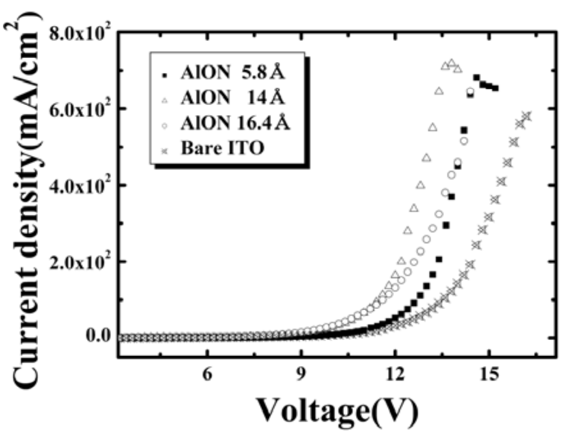


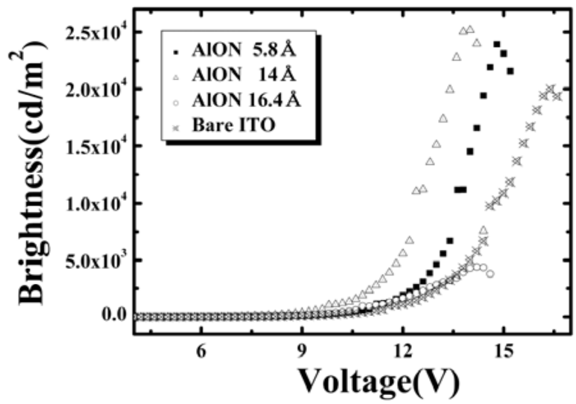
Fig. 1. The device structure of OLEDs with AlON buffer layer

3. Results and discussion

The current density-voltage and brightness-voltage characteristics of the devices under forward bias are shown in Fig. 2(a) and 2(b).



(a)



(b)

Fig. 2. (a) current density-voltage (b) brightness-voltage characteristics without and with buffer layer

As can be clearly seen, the current density-voltage performance of the devices is strongly dependent on the presence and the thickness of the AlON buffer layer. The device with 14Å AlON has the strongest current density and brightness, followed by the 5.8Å and 16.4Å AlON ones. The luminance efficiency of the devices has the similar trend as shown in Fig. 3.

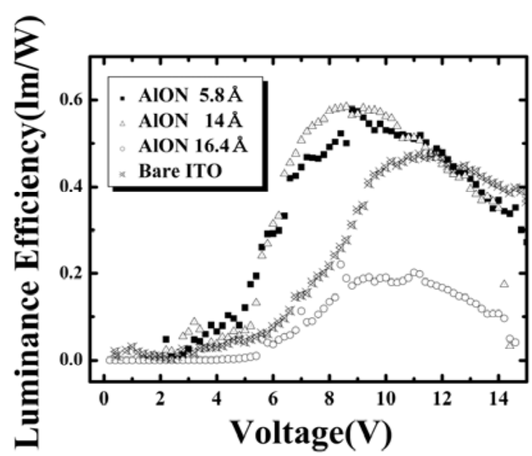


Fig. 3. Luminance efficiency-voltage characteristics without and with buffer layer

As can been seen, the device with 14Å AlON film exhibits the maximum luminance efficiency of 0.58 lm/w, which is higher than that of the device without the buffer layer (0.47 lm/w). However when the AlON thickness is increased further, the luminance efficiency decreases and the value is only 0.20 lm/w for the case of 16.4 Å AlON. This means the existence of an insulating buffer layer, even in optimized thickness, may not always be beneficial to the operation of OLEDs. The enhancements are attributed to an improved balance of hole and electron injections due to the energy level realignment and the change in carrier tunneling probability by the buffer layer [10]. Our experimental results show that the optimum thickness of the AlON buffer layer is around 14Å. In this work, we show a strong evidence that the effects of AlON inserted at the ITO\TPD interface on the hole injection are greatly dependent on the initial barrier height (IBH).

The Fowler-Nordheim tunneling equation is given as follows [11-13]

A generalized equation 1 was used to understand the relationship between I and F.

$$I \propto F^2 \exp(\frac{-k}{F}) \cdots\cdots\cdots\cdots (1)$$

Simplifying equation 1 by taking logs of both sides resulted in equation 2.

$$\ln(\frac{I}{F^2}) \propto -\frac{k}{F} \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where I is the current, F is the electric-field strength, and k is a parameter that depends on the barrier shape.

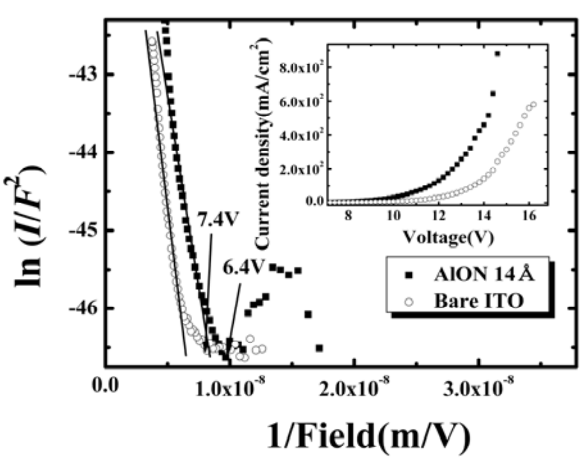


Fig. 4. Fowler-Nordheim tunneling plot with (a) and without (b) AlON treatment of the ITO surface. The curve in the close up shows the current density-voltage (*J-V*) properties of the devices

Fig. 4 shows the plot of ln (I/F^2) versus ($1/F$). The curve appears to be linear with a slope of k. The k values were found to be 9.8952 $\times$ 10^8 and 1.2696 $\times$ 10^8 from the plots shown in Fig. 4 for the case with and without the AlON treatment, respectively. The slope was lower on the device with the AlON treated ITO anode than on the device with the untreated anode. A smaller k value indicates a lower barrier height [13], as a result of which the turn-on voltage of the device becomes lower. The difference in the barrier height ultimately causes a change in the turn-on voltage of the device from 7.4V to 6.4V with a net decrease of 1V, as shown in Fig. 4. Thus, lowering the barrier height to hole injection is especially important, as it leads to a better balance of electron and hole currents and results in a decrease of the driving voltage.

4. Summary

This further confirms that the energy level realignment and the change in carrier tunneling probability are mainly responsible for the variation of current injection induced by the insulating buffers in organic light-emitting. By comparing the devices made without this layer, the results demonstrate that the former has a higher brightness operated at the same current density. This technique provides a new approach to modify the anode and enhance the performance of OLEDs.

5. Acknowledgement

This work was supported by the SRC program (Center for Nanotubes and Nanostructured Composites) of MOST/KOSEF.

6. References

1. C. W. Tang and S. A. VanSlyke, *Appl. Phys. Lett.*, Vol. **51**, p913 (1987).
2. J. Kalinowski, *J. Phys. D.*, Vol. **32**, pR179 (1999).
3. M. Ikai, S. Tokito, Y. Sakamoto, T. Suzuki, and Y. Taga, *Appl. Phys. Lett.*, Vol. **79**, p156 (2001).
4. H. Aziz, Z. D. Popovic, and N. X. Hu, *Appl. Phys. Lett.*, Vol. **81**, p370 (2002).
5. C. Qiu, H. Chen, M. Wong, and H. S. Kwok, *IEEE Trans. Electron Devices*., Vol. **49**, p1540 (2002).
6. Xinjun Xu, Gui Yu, Yunqi Liu and Daoben Zhu, *Displays*., Vol. **27**, p24 (2006).

7. I. H. Campbell, P. S. Davids, D. L. Smith, N. N. Barashkov and J. P. Ferraris, *Appl. Phys. Lett*., Vol. **72**, p1863 (1998).
8. S. A. VanSlyke, C. H. Chen, and C. W. Tang, *Appl. Phys. Lett*., Vol. **69**, p2160 (1996).
9. S. Y. Kim and J.-L. Lee, *Appl. Phys. Lett*., Vol. **87**, p232105 (2005).
10. S. S. Sohn, *J. J. Appl. Phys.,* Vol. **45**, p3733 (2006).
11. V. Bulovic, P. Tian, P. E. Burrows, M. R. Gokhale, S. R. Forrest, M. E. Thompson, *Appl. Phys. Lett*., Vol. **70,** p2954 (1997).
12. V. N. Savvate'ev, M. Tarabia, E. -Z. Farragi, H. Chayet, G. -B. Cohen, S. Kirstein, D. Davidov, Y. Avny, R. Neumann, *Synth. Met*., Vol. **85**, p1269 (1997).
13. I. D. Parker, *J. Appl. Phys*., Vol. **75**, p1656 (1994).