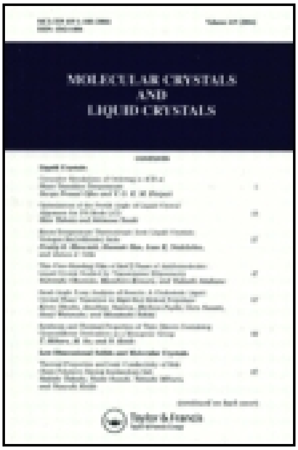

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 17 Oct 2011

To cite this article: Hyun Koo Lee, Ji Hoon Seo, Ji Hyun Seo, Young Kwan Kim & Jun Ho Kim (2006): Investigation on the Effect of 8-Hydroxy-Quinolinato Lithium Between ITO and Hole Transport Layer, Molecular Crystals and Liquid Crystals, 462:1, 277-282

To link to this article: http://dx.doi.org/10.1080/15421400601013437

Mol. Cryst. Liq. Cryst., Vol. 462, pp. 277–282, 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400601013437

Investigation on the Effect of 8-Hydroxy-Quinolinato Lithium Between ITO and Hole Transport Layer

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We investigated the influence of 8-hydroxy-quinolinato lithium (Liq) as the anode buffer layer (ABL) on the performance of the organic light-emitting diodes (OLEDs) with indium tin oxide (ITO) as an anode, N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) as a hole transport layer (HTL), tris-(8-hydroxy-quinolinato)aluminum (Alq_3) as an emitter, Liq as an electron injection layer (EIL) and aluminum (Al) as a cathode. We used Liq with both the ABL and the EIL, respectively. While the ultrathin Liq layer as EIL between Al and Alq_3 modified the electron injection properties, the same layer as ABL between ITO and NPB modified the hole injection properties. We considered that most of the holes move through the anode buffer layer by the tunneling effect. As a result, OLEDs using Liq as ABL showed enhanced luminance efficiency due to good balance between the injected holes and electrons. In this case, the thickness of Liq as ABL had influence on the current density, luminance and device stability. The investigation of various organic materials as ABL will be conducted.

Keywords: anode buffer layer; 8-hydroxy-quinolinato lithium; OLEDs

INTRODUCTION

In recent years, organic light-emitting diodes (OLEDs) have been widely investigated for their applications in full-color flat panel displays [1–6]. Great efforts have been made to improve the performance

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This work is fully supported by the Ministry of Commerce, Industry and Energy.

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of organic light-emitting diodes, for example, we have been using multilayer structures, energy level alignment and low work function cathodes [7–10]. In organic light-emitting diodes, electrons and holes are injected from electrodes into organic materials where they consequently recombine and light emission occurs. In organic light-emitting diodes, electron mobility in organic materials are generally more one order of magnitude lower than the hole mobility. As a consequence, the electroluminescence (EL) efficiency is strongly controlled by the electron current from the cathode to the emissive zone. So, a low work function metal or metal alloy is required to form an effective electron-injecting contact. Although we enhanced the electron injection, yet the balance of electron-hole recombination was not optimized.

In this article, to get the balance optimization [11–14], we used various thickness Liq between anode and HTL as the ABL. The inclusion of the buffer leads to a significant improvement in the efficiency of the devices.

Experiments

OLEDs were fabricated by the high vacuum thermal deposition (8×10^{-7} Torr) of organic materials onto the surface of indium tin oxide (ITO, $30\,\Omega/\square$) coated glass substrate. Prior to film deposition, an ITO coated glass was cleaned in the ultrasonic bath by regular sequence: in acetone, methanol, diluted water and isopropylalcohol. And pre-cleaned ITO coated glass was treated by O_2 plasma treatment which condition is 2×10^{-2} Torr, 125 W, 2 min. The plasma treatment of ITO coated glass causes higher work function anode than bare anode and enhancement of interface effect between anode and organic materials [15–17]. Especially, we controlled thickness of Liq using an electric current and measured it by ellipsometer.

Figure 1 shows the chemical structure of organic materials and the schematic diagram of the device used in this study. OLEDs with Liq as anode buffer layer have a configuration of ITO/Liq (various thicknesses)/NPB (50 nm)/Alq_3(60 nm)/Liq (2 nm)/Al (100 nm). Here, Liq between anode and NPB used as the anode buffer layer, NPB used as the hole transporting layer, Alq_3 used as the emitting layer and electron transporting layer and Liq between Alq_3 and cathode used as the electron injection layer. The optical and electrical properties of OLEDs using the current density (J)-the applied voltage (V)-the luminance (L) characteristics were measured with Keithley 238 and CHROMA METER CS-100A. Both photoluminescence (PL) and electroluminescence (EL) spectra were measured from the Alq_3 powder materials and the device fabricated using a luminescence spectrometer LS50B.

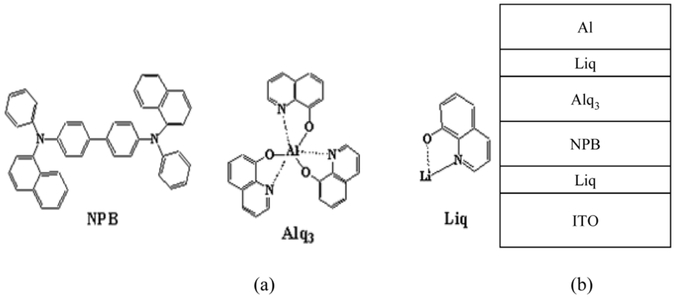

FIGURE 1 Chemical structure of (a) organic materials and (b) schematic diagram of device used in this study.

RESULTS AND DISCUSSION

The PL and EL spectra of the OLED is centered at $\lambda = 510\,\text{nm}$ where green light emits. The PL and the EL spectra exhibited similar characteristics. The device fabricated to have multilayer structure showed the shift of main peak less than 10 nm. To estimate the effect of Liq anode buffer layer, devices were fabricated with various thickness of Liq anode buffer layer.

Figure 2 shows that the current density (J)-the applied voltage (V) characteristics of the device fabricated. It can be seen that the current

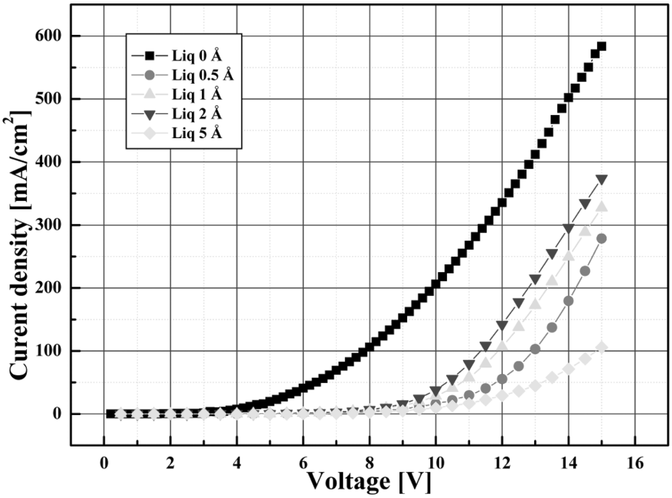

FIGURE 2 Characteristics of the current density (J)-the applied voltage (V) on the devices with the different anode buffer layer thickness.

density of OLEDs are gradually declined as the Liq anode buffer layer thickness increases. This suggested that the anode buffer layer suppresses the hole injection so that, as expected, the current density of the device decreases as the Liq anode buffer layer thickness increases. Therefore we can expect that suppressed hole injection leads to balanced hole and electron concentration in the EML due to excess holes act as the quencher of devices. Except for the device without anode buffer layer, device with 2 Å thick anode buffer layer shows the maximum current density.

Figure 3 shows the characteristics of the luminance (L)-the applied voltage (V) on the devices with the different anode buffer layer thickness. As shown, turn-on voltage of the device without anode buffer layer is about 4 V, and those of others are about 9 V. The maximum luminescence of the devices using anode buffer layer show the diminution. These are evidence of the role of anode buffer layer that anode buffer layer reduced hole injection. In here, except for the device without anode buffer layer, the device with 2 Å thick anode buffer layer shows the maximum luminescence like the current density.

Figure 4 shows the characteristics of the luminous efficiency (LE)-the current density (J) on the devices with the different anode buffer layer thickness. The device with different thickness of Liq anode buffer layer 0 Å, 0.5 Å, 1 Å, 2 Å and 5 Å show the luminous efficiency of 2.73 cd/A, 4.04 cd/A, 4.25 cd/A, 3.82 cd/A and 3.46 cd/A at a given

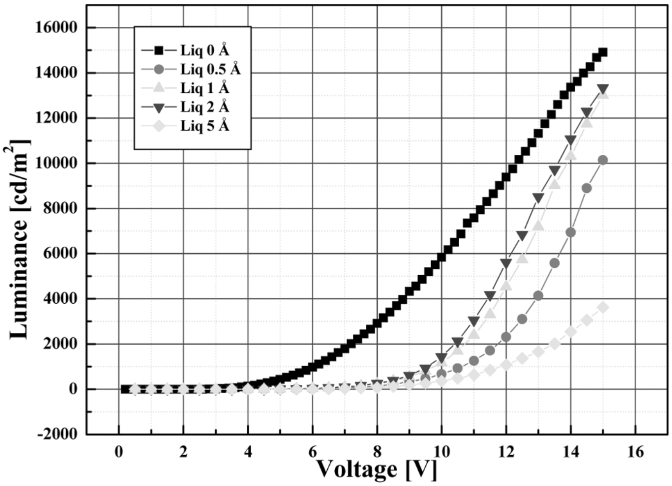

FIGURE 3 Characteristics of the luminescence (L)-the applied voltage (V) on the devices with the different anode buffer layer thickness.

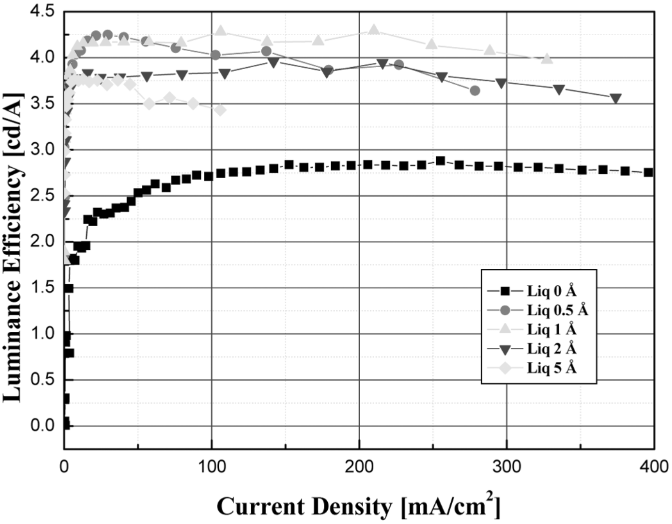

FIGURE 4 Characteristics of the luminous efficiency (LE)-the current density (J) on the devices with the different anode buffer layer thickness.

constant current density of 100 mA/cm^2, respectively. Obviously, the device with 1 Å thick anode buffer layer is efficient one among them. Although the Liq anode buffer layer gives rise to the diminution of the current density and the luminance of the device, the enhancement of the luminous efficiency of the device is certainly shown. Undoubtedly, these enhancement effects may be ascribed to a balanced hole and electron concentration in the EML.

The device efficiency was significantly improved by inserting of Liq anode buffer layer between ITO and NPB layer. In our device structure, ITO/Liq/NPB/Alq$_3$/Liq/Al, While the ultrathin Liq as the electron injection layer between Al and Alq$_3$ enhances the electron injection, the ultrathin Liq as the anode buffer layer between ITO and NPB reduces the hole injection. These effects particularly enhance the balance of electron and hole concentration in the EML. As mentioned above, the device with 2 Å thick anode buffer layer shows the maximum current density and luminance, on the other hand the device with 1 Å thick anode buffer layer shows the maximum luminous efficiency. These are caused by the characteristics of the luminance-the current density. The device with 2 Å thick anode buffer layer has the most efficient characteristics of the luminance-the current density among the device fabricated.

Although the exact role of the Liq anode buffer layer is not completely clear, it is inferred that Liq anode buffer layer enhances the balance of electron and hole concentration in the EML and effects adhesion of NPB to ITO. The exact mechanism to explain the insertion of the anode buffer layer has not been defined yet but will be clarified in the near future.

CONCLUSIONS

In this article, we have shown exact evidence that the role of Liq anode buffer layer is reducing the injected holes in NPB/Alq_3 based device. Although the enhancement of the luminous efficiency is exactly shown, diminution of the current density and the luminance is also shown. The device with 1 Å thick anode buffer layer shows the maximum luminous efficiency because of the most efficient characteristics of the luminance-the current density among the device fabricated. Another merit is reduction of organic material because of dual position of Liq. To investigate the mechanism of the insertion of the ABL, we will investigate various buffer materials.

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