An Inverted Bottom Emission Organic Light Emitting Device with a New Electron Injection Layer.

YouJong Lee, JooHyung Kim, SoonNam Kwon and MunPyo Hong
Dept. of Display and Semiconductor Physics, Korea University, Chungnam, KOREA
TEL:82-41-860-1763, e-mail: lyjong@korea.ac.kr

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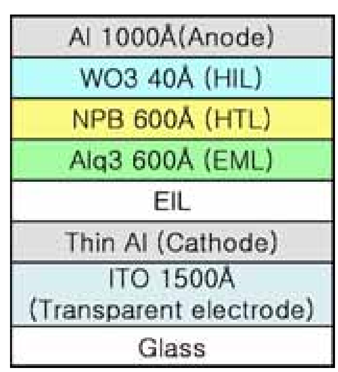
Abstract

Highly efficient inverted bottom emission organic light emitting device (IBOLED) with a structure of ITO/EIL/Alq3/NPB/WO3/Al was investigated. To enhance electron injection from ITO cathode to Alq3 EML layer, we introduced ultra thin Al layer and Liq layer between ITO and Alq3. The device characteristics showed tune on voltage of 4.5V, the maximum luminance of 21100 Cd/m2 and current efficiencies of 3.56 Cd/A.

1. Introduction

Recently, many studies about active matrix organic light emitting device (AMOLED) were introduced. The AMOLED has potential to occupy the biggest part in next generation flat panel display, but need more research about new backplane technology or new OLED structure to realize this. AMOLED back plane can be applied to two types thin film transistors, which are Low-temperature polycrystalline silicon (LTPS) and amorphous silicon (a-Si) thin film transistor. LTPS has higher carrier mobility than a-Si and both n-and p-type TFT can be fabricated. Therefore, a p-type LTPS can be used as the bottom anode of a conventional OLED which is positioned at the drain end of TFT. However, LTPS is not suitable because of expensive fabrication cost and difficult process in large size display. On the other hand, a-Si TFT is inexpensive than LTPS, and has advantage in large size display, but position of bottom and top electrode need to be inverted in OLED structure. Recently, inverted organic light emitting device was introduced by several researchers [1-4]. In the case of a-Si TFT, the channel can be only n-type, so it would be ideal if the connecting electrode of OLED was cathode. But the bottom electrode of normal OLED is anode (ITO), from which holes are injected. So a new device with an inverted structure is required. The inverted structure is consisted of bottom substrate, cathode, electron injection layer, electron transporting (and or light emitting) layer, hole transporting layer, and anode. The direction of emitted light can be bottom or top, according to the electrode formation. If we use ITO as bottom cathode and metal as top anode, the device is inverted bottom emission light emitting device(IBOLED), and if we use metal as bottom cathode and ITO as top anode, the device is inverted top emission light emitting device(ITOLED). In the case of ITOLED, we have developed new ITO film formation process on organic layers without serious plasma damages. The process is called neutral beam based sputtering process [3]. But we firstly concentrated on IBOLED for adapting to a-Si TFT based AMOLED for large sized TV applications. In the case of IBOLED, the remained problem was electron injection layer. In some previous works, the authors used a thin Mg layer as electron injection layer. But Mg is a very reactive material which needs careful precaution for use. Our work suggests a new electron injection layer which can be used in conventional OLED fabrication process.

2. Experimental



	Device A	Device B	Device C
Cathode/EIL Materials	ITO / Thin Al / LiF	ITO / Cs	ITO / Thin Al / Liq

Fig. 1. Structure of standard IBOLED.

As shown in Fig 1., the standard device has structure of ITO / Thin Al layer / EIL / Alq3 / NPB / WO3 / Al. The substrates used ITO-coated glass, and the thickness and sheet resistance of the ITO were 1500Å and 20Ω/□, respectively. The ITO-coated glass substrates were cleaned by the general wet sequence procedure and UV O_3 surface treatment. Then Al electrode and organic emitting layer was deposited by thermal evaporation at a vacuum of 10^{-7}Torr. The metal evaporation chamber is connected to the organic evaporation chamber by load lock system. Therefore the vacuum is not broken during the deposition process. The thickness of thin cathode Al layer was varied from 3Å to 100Å, and three different types of EIL materials were deposited. Device A. has structure of ITO 1500Å / thin Al / LiF / Alq3 600Å / NPB 600Å / WO3 40Å / Al 1000Å, Device B. has structure of ITO 1500Å / Cs / Alq3 600Å / NPB 600Å / WO3 40Å / Al 1000Å, and Device C. has structure of ITO 1500Å / thin Al / Liq / Alq3 600Å / NPB 600Å / WO3 40Å / Al 1000Å. The active area of the IBOLED, defined by the overlap of the ITO and the cathode electrodes, was $2 \times 2 mm^2$. The current density–voltage–luminance (J–V–L) characteristics of the devices were measured with a Photo Research PR650 spectrophotometer and a Keithley 236 computer-controlled programmable dc voltage source.

3. Results and discussion

Generally, the performance of IBOLED with ITO bottom cathode is poorer than with Al bottom cathode, because work function of ITO (4.7 eV) is higher than Al (4.2 eV). Therefore, the Al layer is stacked on the ITO electrode. Chen et al.[4] has reported the use of an ultrathin Alq3–LiF–Al trilayer as an effective composite electron injection layer for the bottom Al and Ag cathodes in inverted top emitting OLEDs. The chemical reaction for ultrathin Alq3/LiF/Al trilayer electron injection is expressed as

$$\mathbf{3LiF + Al + 3Alq3 \Rightarrow AlF3 + 3Li^{+}Alq3^{-}}$$

in which [$Li^{+}Alq3^{-}$] is believed to be the active injecting species. However, in IBOLED structure, thick aluminum electrode causes decrease brightness and microcavity effect. So, appropriate thickness of Al bottom cathode is an important factor in IBOLED structure. To find out most suitable thickness, we fabricated IBOLED with different Al thickness, varying from 3 Å to 100 Å. The Al 3Å and 5Å device

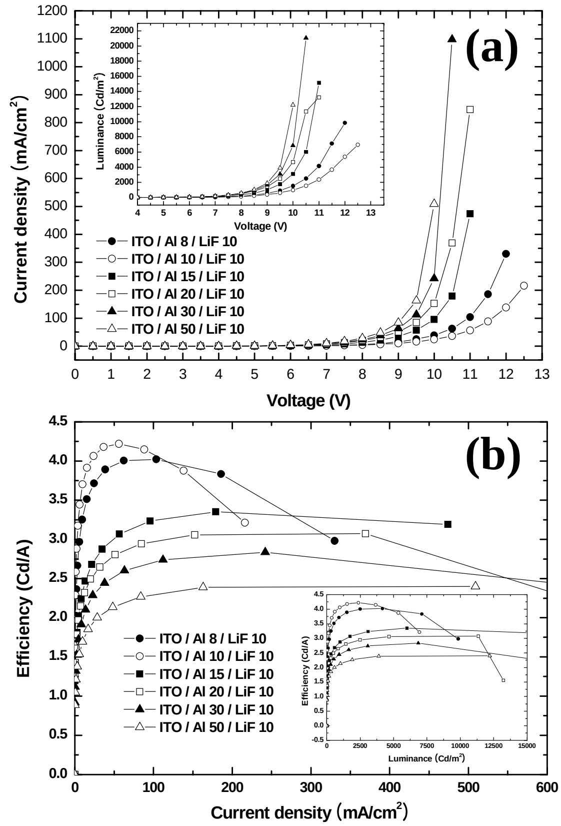


Fig. 2. (a) J/V and L/V, (b) Efficiency characteristic of 'Device A' with different thin Al cathode layer thickness.

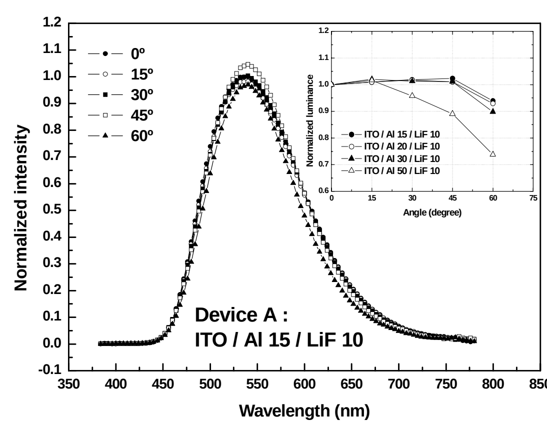


Fig. 3. Measured EL spectra with changed the angle from 0° to 60°, and (Inset) Measured Luminance with changed the angle from 0° to 60°.

did not show good performances, and luminance of devices with Al from 50Å to 100Å was very low. Therefore, ideal thickness of thin Al bottom cathode

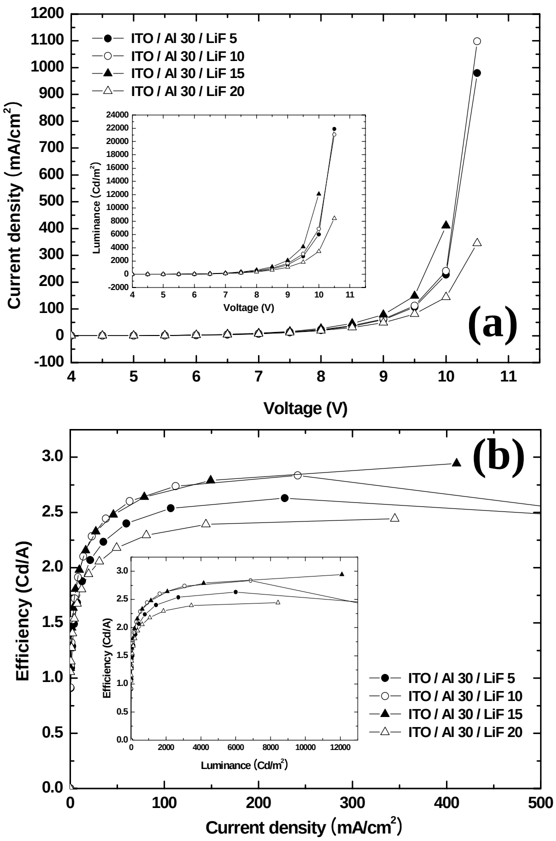


Fig. 4. (a) J/V and L/V, (b) Efficiency characteristic of ‘Device A’ with different LiF layer thickness.

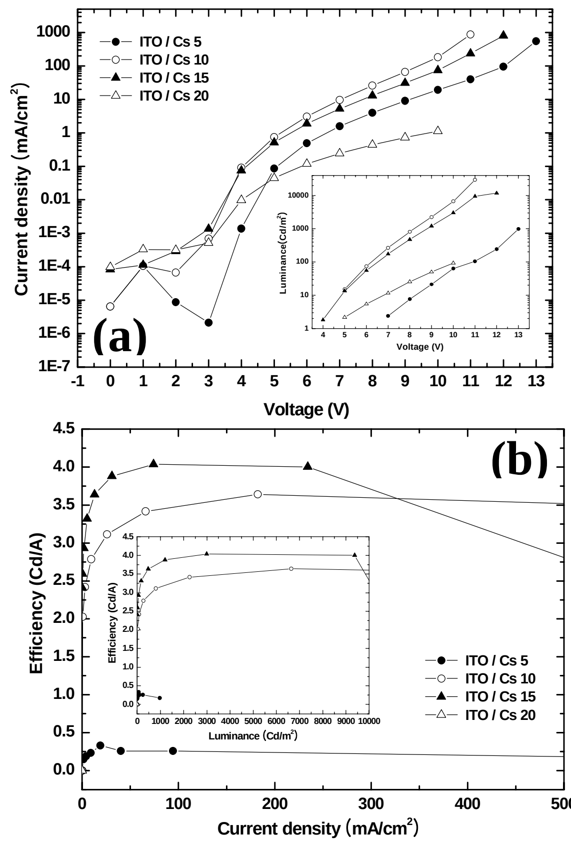


Fig. 5. (a) J/V and L/V, (b) Efficiency characteristic of ‘Device B’ with different Cs layer thickness.

was chosen from 8Å to 50Å. Figure 2. illustrates the IBOLED characteristics with changed Al bottom cathode thickness to 'Device A'. The Al bottom cathode 50Å device was operated at 4.5V, and current density of 100mA/cm^2 was reached at around 9.0V. However, thick Al bottom cathode caused lower luminance efficiency. The Al bottom cathode thickness of 8Å and 10Å device showed relatively low device performance than Al bottom cathode from 15Å to 30Å device. Therefore, for better JVL and efficiency characteristics, Al bottom cathode’s most suitable thickness is from 15Å to 30Å, and device of Al thickness 15Å showed the highest efficiency. The device with Al bottom cathode 15Å was operated at 4.5V, maximum luminance was 15120 cd/cm^2 at 11V, and maximum luminance efficiency was 3.35 cd/A. Figure 3. is the curve of measured EL spectra for various tilted angle from 0 to 60 in the device with Al bottom cathode 15Å. The change of EL spectra curve and luminance difference (inset) were very small with respect to tilted viewing angles, which means that the IBOLED with 15Å thick Al does not show micro-cavity effect [5]. Figure 4. shows the current density, luminance, and current efficiency curve of 'Device A' with Al bottom cathode thickness of 30Å. The LiF electron injection layer thickness was changed from 5Å to 20Å. The LiF 5Å and 10Å IBOLED showed similar JVL characteristics, but luminance efficiency of IBOLED with 10Å LiF was better than with 5Å LiF. The LiF 15Å IBOLED operated at 4.5V, and current density of 100mA/cm^2 was reached at around 9.2V, but maximum luminance was lower than LiF 10Å device. The operating voltage of LiF 10Å IBOLED was 4.5V, and maximum luminance was 21060 cd/cm^2 at 10.5V, luminance efficiency was 2.8 cd/A. The current density of 100mA/cm^2 was reached at around 9.5V. Figure 5. shows characteristics of IBOLED using Cs as an electron injection layer. The Cs thickness was changed from 5Å to 20Å in 'Device B'. The luminance efficiency of IBOLED with 15Å Cs was achieved 4.0 cd/A, but maximum luminance and efficiency stability were lower than Cs 10Å device. The Cs 10Å device was operated at 5V, maximum luminance was 29500 cd/m^2 at 11V, and maximum

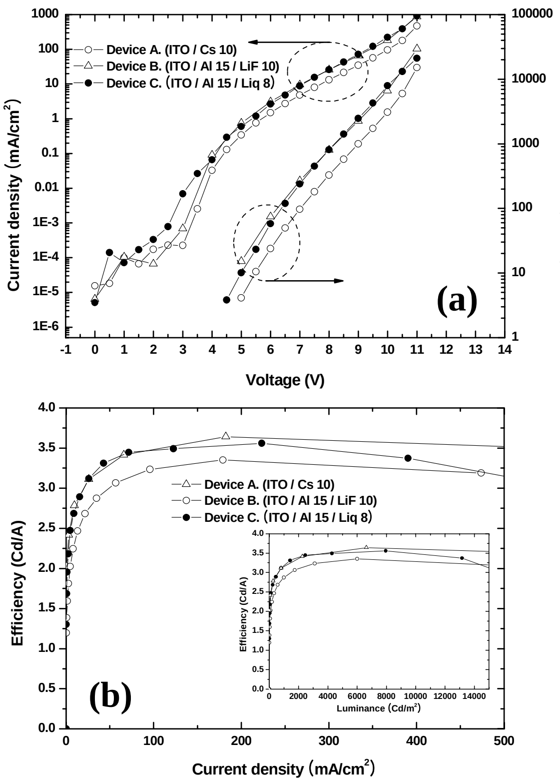


Fig. 6. (a) J/V and L/V, (b) Efficiency characteristic of 'Device A', 'Device B' and 'Device C'

efficiency was 3.64 cd/A. In 'Device C', 8Å Liq was used as electron injection layer. The turn on voltage was 4.5V, and the threshold voltage was around 2.5 V. The maximum luminance of 21100 cd/m^2, and current density of 100mA/cm^2 were achieved at 11V and around 9.2V, respectively. The maximum luminance efficiency was 3.56 cd/A. Comparing 'Device A' with 'Device C', the efficiency of Liq as electron injection layer is better than LiF as electron injection layer, especially, the device with Liq as EIL showed the best characteristics at turn on voltage and threshold voltage. The luminance and efficiency characteristics of Device B. were better than Device C., but Liq is a relatively stable organic material, also the fabrication is easier than Cs. Therefore, the Liq and thin Al bottom cathode would be the most suitable EIL structure to IBOLED, if we consider both performance and mass production.

4. Summary

The previous works used very reactive metals for electron injection layer of IBOLED such as Mg, Li or Cs. The Liq is a relatively stable organic material which is widely used in OLED industry, and electron injection efficiency is also good. Therefore, the new electron injection layer using Liq suggested in this work is supposed to be used in common OLED fabrication process.

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