Effects of indium tin oxide top electrode formation conditions on the characteristics of the top emission inverted organic light emitting diodes

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Abstract

Indium tin oxide (ITO) was used as the top anode of top emission inverted organic light emitting diodes (TEIOLEDs). TEIOLEDs were fabricated by deposition of an aluminum bottom cathode, an N,N′-diphenyl-N,N′-bis(3-methylphenyl)-1,1′-diphenyl-4,4′-diamine (TPD) hole transport layer, a tris-8-hydroxyquinoline aluminum (Alq_3) emission layer, and an ITO top anode sequentially. ITO was deposited by r.f. magnetron sputtering without O_2 flow during the deposition. After the deposition, the deposited ITO layer was kept under oxygen atmosphere for the oxidation. The characteristics of the TEOILED were affected significantly by the post-deposition oxidation condition.

1. Introduction

Organic light-emitting diodes (OLEDs) have been attracting a great deal of attention for potential use as full-color flat panel displays in the next generation. In particular, top emission OLEDs (TEOLEDs) will be very useful because TEOLEDs can emit light through the top electrode, and in the presence of thin film transistor arrays lying under the OLEDs, as is the case of active matrix displays, higher portion of the emitted light can be utilized compared to the bottom emission OLEDs (BEOLED) [1-6]. One of the approaches to fabricate TEOLEDs is to just invert the fabrication process of BEOLEDs, *i.e.*, to deposit the constituting layers of OLEDs in the sequence of a metal cathode, organic layers, and an indiun-tin-oxide (ITO) anode. TEOLEDs fabricated by the aforementioned method can be referred to as top emission inverted OLEDs (TEIOLEDs). For the fabrication of TEIOLEDs, care must be taken when the top ITO electrode is formed due to the possible damage of underlying organic layers during the formation of the ITO layer. In this work, we report effects of ITO top electrode formation conditions such as oxidation pressure and time on the characteristics of the TEIOLEDs.

2. Experiments

Figure 1 shows the structure of TEIOLEDs used in this work. Aluminum (Al), tris-(8-hydroxyquinoline) aluminum (Alq_3) and N,N′-diphenyl-N,N′-bis(3-methylphenyl)-1,1′-diphenyl-4,4′-diamine (TPD), ITO were used as a cathode, an emitting layer (EML), and a hole-transporting layer (HTL), and an anode, respectively. The thicknesses of Al, Alq_3, TPD, ITO were 150, 48, 32 and 100 nm, respectively. Deposition rates for the organic layers and the cathode layer were 1.5-2.0Å/s and 5.0-8.0Å/s, respectively.

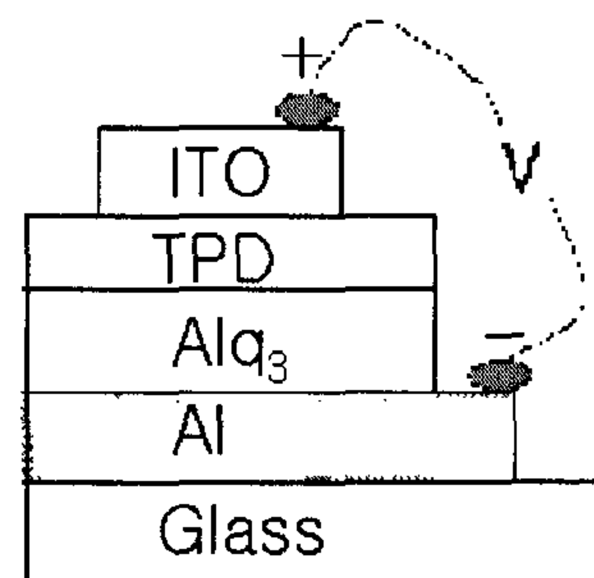

Figure 1. Structure of theTEIOLED.

After deposition of the cathode and the organic layers on the glass substrate, the sample was immediately transferred to a sputter deposition chamber with a base pressure of 5×10^{-6} torr. The ITO

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electrode was formed on top of the glass/Al/Alq_3/TPD by sputter deposition and subsequent oxidation in the sputter deposition chamber. The ITO layer was deposited by low-power r.f. sputtering. The target, housed in a magnetron sputtering gun, is 10% SnO_2 and 90% In_2O_3 by weight with 99.99% purity. The sputtering gas is a 99.999 % pure argon (Ar). The total pressure during the sputtering process is 6×10^{-3} torr, with the Ar flows regulated by mass flow controllers at 100sccm. The r.f. sputtering power is 30 W, resulting in a deposition rate of 0.8 Å/s. The sheet resistance of a 100nm thick as-deposited film is 200 Ω/□, which is sufficiently small for making top contacts. In our work, since O_2 flowing during the sputter deposition of ITO seriously degraded the characteristics of the TEIOLEDs, O_2 was not flowed into the sputter deposition chamber during the sputter deposition of ITO. To optimize the properties of the ITO electrode, oxygen (O_2) was flowed into the deposition chamber after sputter deposition of ITO. The TEIOLEDs were operated in air for all the experiments. A Keithley 2400 electrometer was used for current density-voltage characteristics as a voltage source and current measurement equipment. Brightness of the TEIOLEDs was investigated by measuring the photocurrent induced by the light emission from the TEIOLEDs using the Keithley 485 picoammeter.

3. Results and discussion

The forward-biased current density versus voltage (J-V) characteristics of the TEIOLED is shown in Fig. 2. Figure 2(a) shows change of the J-V curves with the pressure variation of O_2, which was flowed into the deposition chamber for oxidation after r.f. sputter deposition of ITO. O_2 pressure was varied in the range of 0.7-3.0 torr. TEIOLEDs whose ITO was oxidized with O_2 pressure of 0.7, 0.8, and 3.0 torr were referred to as TEIOLED(0.7), TEIOLED(0.8), and TEIOLED(3.0), respectively. The oxidation time, which refers to the time during which the TEIOLED was kept under O_2 pressure, was fixed at 20 min. In Fig. 2(a), the turn-on voltages of TEIOLED(0.7), TEIOLED(0.8), and TEIOLED(3.0) were observed at 18.0 V, 17.0 V and 5.6 V, respectively. As the oxidation pressure increased, the current through the TEIOLED increased. The increase of current is thought due to the increase of oxygen concentration in the ITO layer, as was reported previously in ref. [7], where it was suggested that the current increase was caused by the improvement in hole injection due to the oxygen concentration increase in the ITO layer.

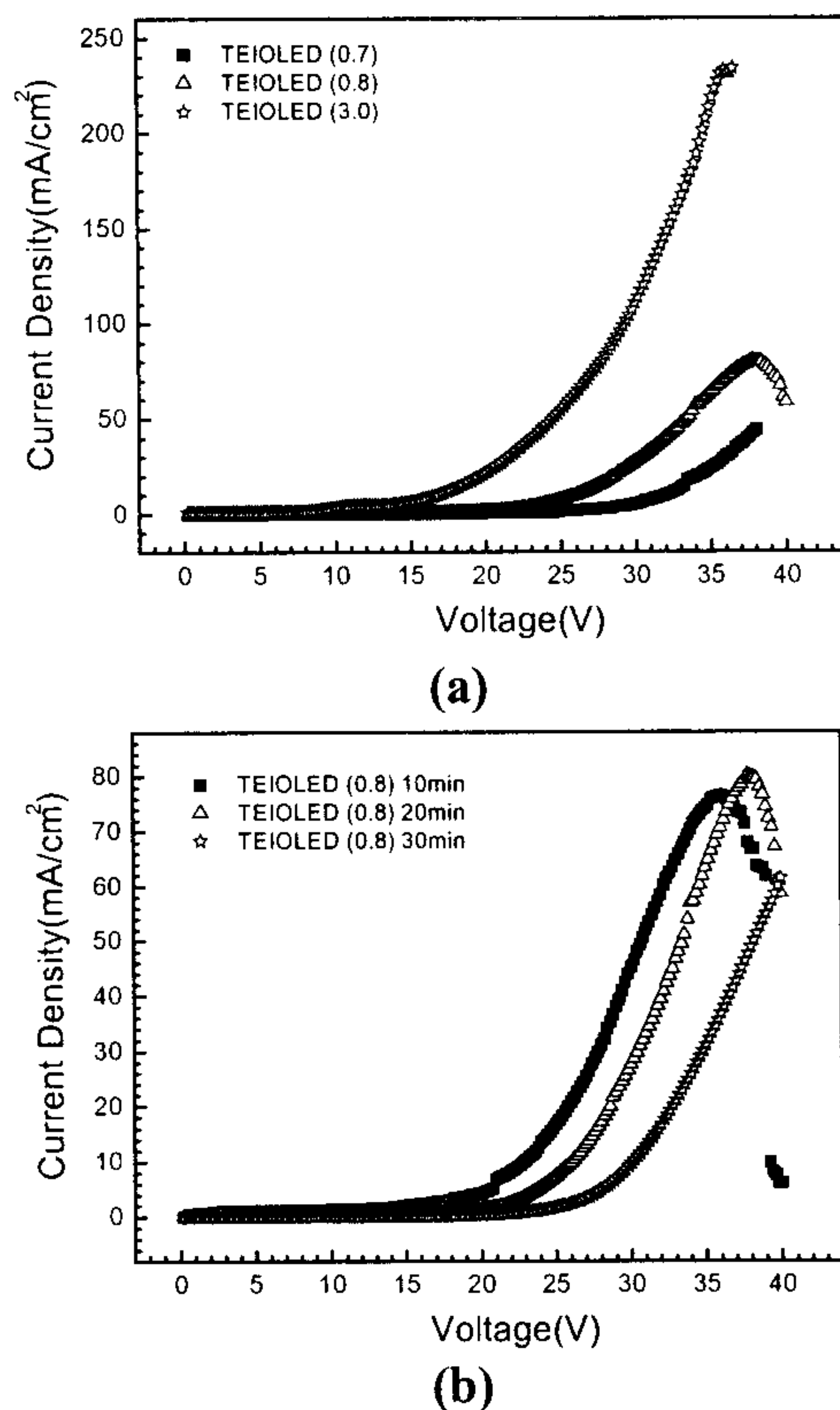
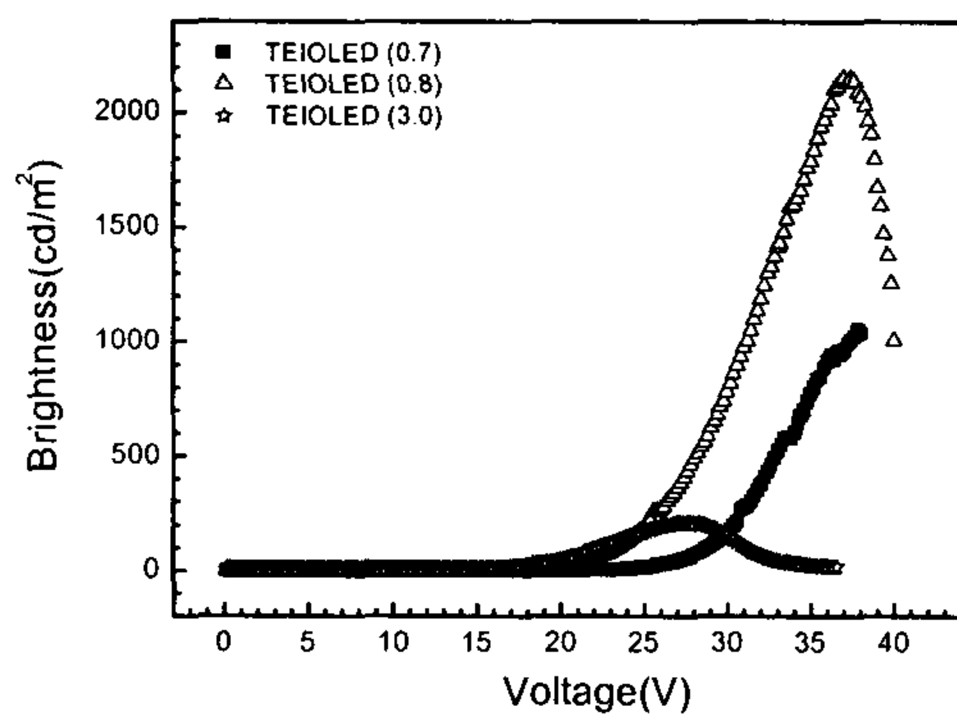


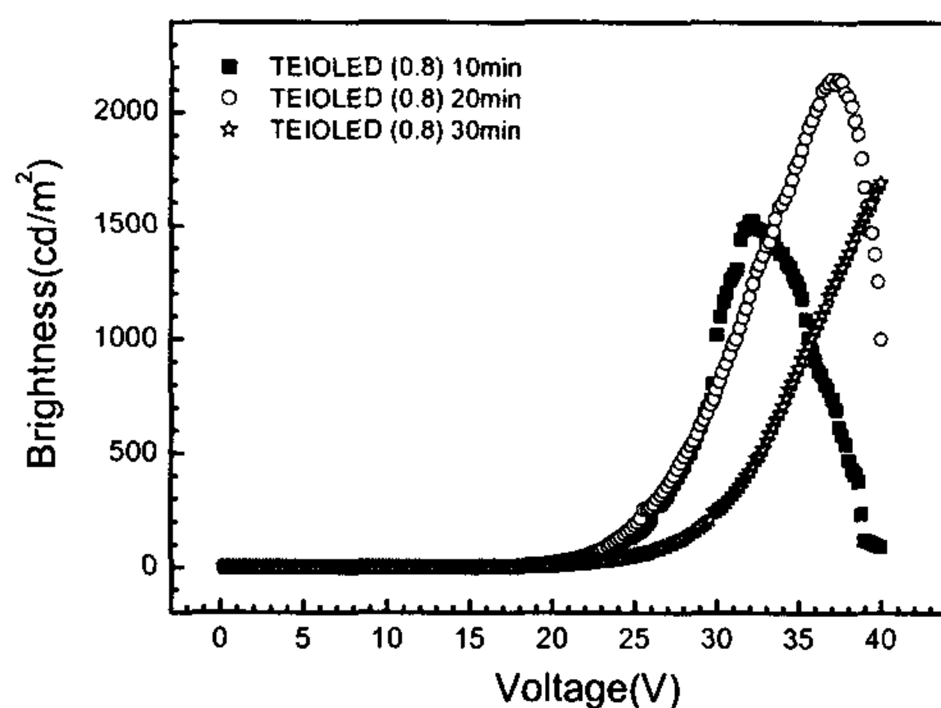
Figure 2. (a) J-V characteristics of the TEIOLED with various ITO oxidation pressures. (b) J-V characteristics of the TEIOLED(0.8) with various ITO oxidation times.

Figure 2(b) shows change of J-V characteristics of the TEIOLED(0.8) with the variation of ITO oxidation time. Three oxidation times of 10, 20, and 30 min were used. As the ITO oxidation time increased, the TEIOLED showed lower current. Long exposure of the TEIOLED to O_2 is considered to degrade the organic layers lying under the ITO layer. Figure 3 shows the brightness versus applied voltage (B-V) of TEIOLEDs. Figure 3(a) shows change of the B-V curves with the O_2 pressure variation for a fixed oxidation time of 20min. As the O_2 pressure increased from 0.7 to 0.8 torr, the TEIOLED showed higher brightness. However, further increase of O_2 pressure degraded the brightness of the TEIOLEDs. It is considered that increase of O_2 pressure up to the optimum pressure helps to improve the quality of the ITO electrode and the performance of TEIOLEDs, however, too high O_2 pressure degrades the TEIOLED performance possibly due to the damage of

the organic layers by O_2.



(a)



(b)

Figure 3 (a) B-V characteristics of the TEIOLED with various ITO oxidation pressures. (b) B-V characteristics of the TEIOLED(0.8) with various ITO oxidation times.

The maximum brightness of TEIOLED(0.8) was 2149 cd/m^2 at 36 V and the visible light turn-on was about 12 V. Figure 3(b) shows the B-V characteristics of the TEIOLED(0.8) with the variation of ITO oxidation time. The TEIOLED(0.8)s with ITO oxidation times of 10 min and 20 min showed similar turn–on voltages. However, the TEIOLED with 20 min oxidation time showed higher maximum brightness than the TEIOLED with 10 min oxidation time. Brightness of the TEIOLED with 30 min oxidation time was lower than TEIOLEDs with 10 or 20 min oxidation time.

4. Conclusion

In conclusion, TEIOLEDs were fabricated by depositing the constituting layers of OLEDs in the sequence of the Al cathode, the Alq_3 EML, the TPD HTL, and the ITO anode. The characteristics of the TEIOLED were affected significantly by the ITO post-deposition oxidation conditions such as oxidation pressure and time. In our work, as the oxidation pressure increased and the oxidation time decreased, the current through the TEIOLED increased. In case of brightness, there were optimum oxidation pressure and time, which were 0.8 torr and 20 min, respectively.

5. References

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