Effective structure of electron injection from ITO bottom cathode for inverted OLED

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Abstract

For display drivers employ typically a-Si n-channel field effect transistors, they require an inverted OLED structure with a cathode as the bottom contact. ITO is regarded as the bottom cathode and can be applied to large size AM-OLED and transparent inverted OLEDs. We report the effective structure to improve the efficiency of electron injection from ITO cathode to Alq_3. We report the effective structure to improve the efficiency of electron injection from ITO cathode to Alq_3 and studied the current density-voltage characteristics of trilayer (Alq_3-LiF-Al), LiF and Mg inserted between ITO and Alq_3, respectively. We discovered that 1 nm Mg afforded the highest efficiency.

Objectives and Background

The component of conventional bottom-emitting OLEDs is to evaporate the organic materials on transparent indium-tin-oxide (ITO) anode substrate and covered with the reflective layer as cathode. The n-channel a-Si field effect transistor with high mobility is regarded as ideal for future large area and low cost active matrix display. It is desirable that the bottom contact of the OLED be the cathode. Forrest et al[1] used reflection of MgAg as the base substrate, and sputtered ITO above organic layers to make the inverted top emitting OLED. But the intense radiation energy caused by sputtering would damage the organic layer and the gap states created would induce more nonradiative relaxation of injected carriers.[2] In relevant researches reported, certain protective capping layers have been used as buffer for reducing the sputtering damage.[1,3,4,5] There are studies reported that replacing the ITO anode by gold[6] and TeO_2/Ag[7] thin film is effective to fabricate inverted OLED. Coupled with the transparent cathode of ITO, this methodology can also make transparent inverted OLED,[8]

In generally, cathode and anode in OLEDs are demanded to have low and high work function respectively. Because the lower work function material such as Al/LiF or Mg:Ag of cathode can be made to inject electron into organic layer. On the other hand, high work function of ITO is most suited to function as anode in conventional OLED. However, one of the major challenges in inverted OLEDs is to prepare a bottom cathode providing effective electron injection, especially when using transparent ITO of high work function as cathode. In this paper, we studied the device structures for enhancing the electron-injection capability of the ITO cathode in inverted OLEDs.

Results and discussion

Recently, C. C. Wu et al[7] has reported the use of the ultrathin Alq_3-LiF-Al trilayer as an effective composite electron injection layer for bottom Al and Ag cathodes of inverted top-emitting OLEDs. The chemical reaction for the ultrathin Alq_3/LiF/Al trilayer to inject electron injection has been expressed as:

$$3\ LiF + Al + 3\ Alq_3 \rightarrow AlF_3 + 3\ Li^+Alq_3^-$$

in which $[Li^+Alq_3^-]$ is believed to be the active injecting species.

However, we find the efficiency of electron injection by Alq_3-LiF-Al trilayer only makes a limited improvement upon using ITO as the cathode that is not as good as one which uses Al or Ag instead. Figure 1 shows the current–voltage characteristics of the devices with the structure of ITO substrate (cathode)/ trilayer /Alq_3 (80nm)/LiF (1nm)/Al (100nm, anode) in comparison with the same device structure without the trilayer. Although the trilayer appeared to enhance the efficiency of the electron injection, we will show in this paper that there is a better choice.

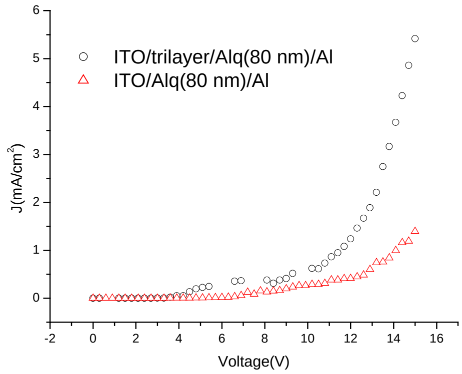

Fig. 1 J-V characteristics of ITO as the bottom cathode with and without the ultrathin Alq_3-LiF-Al trilayer.

The optimized thickness of LiF inserted between Alq_3 and Al is 1nm in conventional bottom-emitting OLED component. But when used in inverted OLED component with ITO as the bottom cathode, we have discovered that LiF can also increase electrons injection efficiency as shown in Fig. 3. Schlaf et al[9] reported that the work function is reduced as the LiF layer is evaporated on Al surface. We propose that the ITO work function can also be reduced because of the of the LiF layer and the electron injection efficiency is improved. We noted that the optimal thickness of LiF between ITO and Alq_3 is 3 nm not merely 1nm as depicted in Fig. 2 for the thickness of the buffer-layer is dependent upon the initial energy barrier.[10] Therefore, the different cathode and organic materials which have different initial energy barriers necessitate the thickness of Li be optimized. The efficiency of electron injection from the optimized LiF layer is determined to be better than that of the Alq3/LiF/Al trilayer.

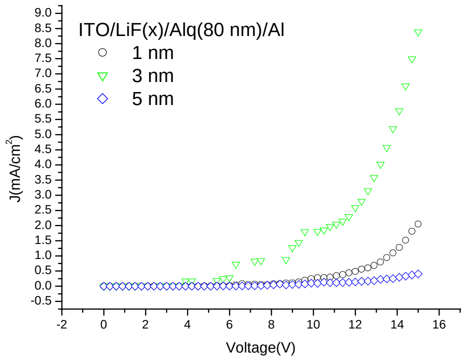

Fig. 2. J-V characteristics of different LiF thickness inserted between ITO and Alq_3.

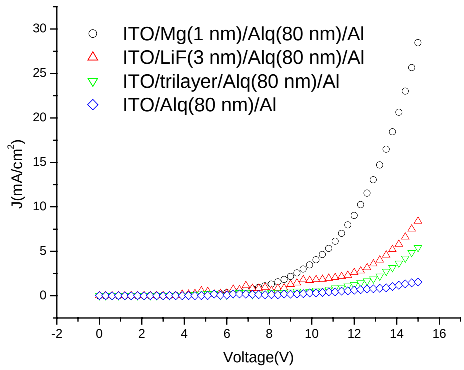

Fig. 3. Comparison of the J-V characteristics of trilayer, LiF and Mg as electron injection layer over ITO as cathode.

Additionally, we find that magnesium as low work function metal deposited on ITO surface can also improve the electron injection efficiency [Fig. 3]. However, the best thickness for magnesium is only 1 nm, and thicker Mg produced no better efficiency as shown in Fig. 4. We suggest that the results could be rationalized from the charge transfer dipole model. The electrons of the magnesium is moved strongly toward ITO surface which induces a charge transfer dipole and in turn, reduces the barrier height between ITO and Alq_3 with low coverage of magnesium. The sketch map of surface is shown in Fig. 5(a). Because ITO surface is not the ideal, we think the 1 nm of magnesium is unable to form an intimate contact membrane on the surface. When the thickness of the magnesium increases gradually, the surface forms a magnesium membrane which reduces the interfacial electron transfer and the electronic interaction among magnesium atoms [Fig. 5(b)].

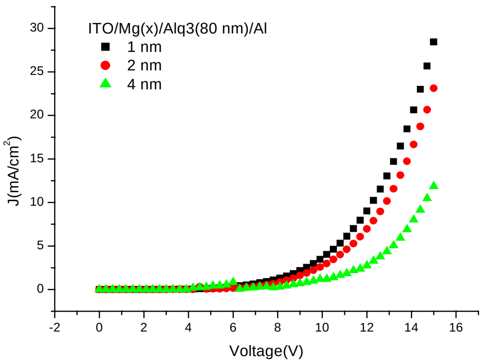

Fig. 4. J-V of different Mg thickness deposited between ITO and Alq_3.

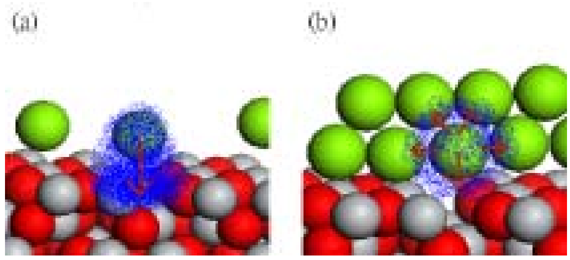

Fig. 5. Sketch map showing the magnesium electrons distributed onto the surface of ITO. (a), Electrons are moved toward the surface and induce a large surface dipole with low coverage, (b) After forming the membrane of the magnesium, the surface dipole is reduced due to the interaction among magnesium atoms.

Summery

We report three kinds of ultrathin layers as an effective composite electron injection layer for bottom ITO cathodes of inverted OLEDs. Although the trilayer and LiF that have been reported can enhance the efficiency of electron injection above Al or Ag as cathode, it is not as effective when ITO used as cathode. In this present work, we discovered that the best efficiency of electron injection from ITO cathode is by inserting 1nm of Mg between ITO and Alq_3.

Acknowledgements

This work was supported by grants from Chunghwa Picture Tubes, Ltd. (CPT) of Taoyuan, Taiwan, who also provides a scholarship for T.-Y. Chu to pursue his advanced studies at DI/NCTU. Additional support was provided by the Ministry of Education of Taiwan, Republic of China under the grant of *PPUAE (91-E-FA04-2-4-B)*.

Reference

[1] V. Bulovic, P. Tian, P. E. Burrows, M. R. Gokhale, S. R. Forrest, and M. E. Thompson, Appl. Phys. Lett. 70, 2954 (1997)

[2] L. S. Liao, L. S. Hung, W. C. Chan, X. M. Ding, T. K. Sham, I. Bello, C. S. Lee, and S. T. Lee, Appl. Phys. Lett. 75, 1619 (1999)

[3] T. Dobbertin, M. Kroeger, D. Heithecker, D. Schneider, D. Metzdorf, H. Neuner, E. Becker, H.-H. Johannes, and W. Kowalsky, Appl. Phys. Lett. 82,284 (2003)

[4] T. Dobbertin, O. Werner, J. Meyer, A. Kammoun, D. Schneider, T. Riedl, E. Becker, H.-H. Johannes, and W. Kowalsky, Al. Phys. Lett. 83, 5071 (2003)

[5] M. Pfeiffer, S.R. Forrest, X. Zhou, K. Leo, Org. Elec. 4, 21 (2003)

[6] X. Zhou, M. Pfeiffer, J. S. Huang, J. Blochwitz-Nimoth, D. S. Qin, A. Werner, J. Drechsel, Appl. Phys. Lett. 81, 922 (2002)

[7] Chieh-Wei Chen, Chun-Liang Lin, and Chung-Chih Wu, Appl. Phys. Lett. 85, 2469 (2004)

[8] M. Pfeiffer, S.R. Forrest, X. Zhou, K. Leo, Org. Elec. 4, 21 (2003)

[9] S. E. Shaheen, G. E. Jabbour, M. M. Morell, Y. Kawabe, B. Kippelen, and N. Peyghambarian, M.-F. Nabor, R. Schlaf, E. A. Mash, and N. R. Armstrong, J. Appl. Phys. 84, 2324 (1998)

[10] J. M. Zhao, Y. Q. Zhan, S. T. Zhang, X. J. Wang, Y. C. Zhou, Y. Wu, Z. J. Wang, X. M. Ding, X. Y. Hou, Appl. Phys. Lett. 84, 5377 (2004)