The triple layer anode for flexible top emission organic light-emitting devices

Sung Mook Chung*, Chi-sun Hwang, Jeong-Ik Lee, Sang Hee Ko Park, Yong Suk Yang, Lee-Mi Do, and Hye Yong Chu
IT Convergence & Component Laboratory, Electronics and Telecommunications Research Institute, 161 Gajeong-dong, Yuseong-gu, Daejeon 305-700, Korea
TEL:82-42-860-1063, e-mail: smchung@etri.re.kr.
Keywords : TEOLED, triple layer, anode, bending test, crack-free

Abstract

A top emission organic light emitting diode comprising of a triple anode on polycarbonate film/TNATA/NPB/Alq_3:C545T/cathodes has been fabricated. The triple layer structure of Cr/Al/Cr allowed for fabrication of a crack-free anode and provided better higher work function than ITO anode.The anode showed compatibility with flexible plastic substrate and no crack was formed during bending test while ITO anode showed crack.

1. Introduction

Organic light-emitting devices (OLEDs) have attracted wide attention because of their potential application to flat panel display.[1] Over the past few years, stainless steel foil, ultra-thin glass sheet, and a variety of plastic films have been considered for flexible OLED displays. Flexible displays based on OLED offer many potential benefits over other display technologies, including reductions in weight and thickness, improved ruggedness, and nonlinear form factors. However, the electrical characteristic of switching device on flexible substrate is inferior to that on rigid substrate. Therefore, TEOLED is more important to obtain high aperture ratio in flexible AMOLED. [2,3] In TEOLEDs, high reflectivity of bottom anode is essential for achieving high luminance efficiency.[4] Moreover, compatibility with flexible substrate is crucially required to realize flexible display. The high residual stress and stiffness of metal layer or transparent conductive oxide (TCO) layer make it difficult to use as an on flexible substrate.[5] In this presentation, we report on TEOLED based on the triple layer anode on flexible substrate with bending test.

2. Experimental

The polycarbonate (PC) sheet was used as a substrate for this study. The structure of the anode was Cr/Al/Cr and indium thin oxide (ITO) was used for comparison. Reflective and opaque Cr anodes were patterned by photolithography and wet etching. The Cr and Al layers were grown by dc magnetron sputtering. The base vacuums for the sputtering and thermal evaporation were approximately 5 x 10^{-7}. The edge of the anode was passivated using an organic material to prevent short failure between the cathode and the anode. To investigate the flexibility of the triple layer anode on PC substrate, we have devised a bending test system.(figure 1) The substrate of 20 mm × 20 mm size was rolled with the diameter 2 mm circle.

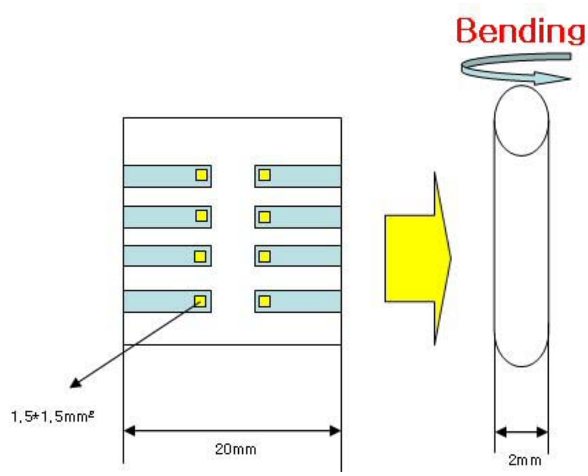

Fig. 1. Bending test process model.

The substrates containing patterned anodes were routinely cleaned and treated with oxygen plasma at

150W for 1 min before loading into a thermal evaporation chamber with base vacuum of 5 x 10^{-7} Torr. The device structure of TEOLED grown by thermal evaporation was 4,4′,4″-tris[2-naphthyl(phenyl)amino]triphenylamine (2-TNATA)/α-napthylphenylbiphenyl diamine (NPB)/tris(8-hydroxyquinoline) aluminum (Alq_3)/LiF/Al/Ag/NPB. The multilayer of LiF (1 nm)/Al (1.5 nm)/Ag (15 nm) was used as a cathode.

Electroluminescence spectra were obtained using a Minolta CS-1000. The current/voltage and luminescence/voltage characteristics were obtained using a current/voltage source/measure unit (Keithley 238) and a Minolta LS-100.

3. Results and discussion

Metal/ITO has been used as an anode for TEOLED, however, brittle property of ITO is a problem for flexible display. Ag is also widely used, however, it is difficult to pattern Ag layer for display application. Here, we have come up with a new anode based on Al and Cr for flexible TEOLED.

Al provides flexibility and high reflectivity as well as easy patterning process. Cr is used for good adhesion and low injection barrier. Therefore, the triple layer of Cr/Al/Cr has been developed to meet the requirements for TEOLED on flexible substrate.

The thickness of the brittle Cr layer was decreased to prevent possible crack of the metal film after bending of the substrate. Al layer was used to buffer the Cr layer and increase the conductivity and reflectivity of the anode layer. The thickness of Cr and Al layers and sputtering conditions have been optimized to obtained best performance in TEOLED and flexibility. The optimized anode structure of 100Å Cr/2000Å Al/100Å Cr was obtained.

Figure 2 shows the optical microscope images of anodes before and after bending test. As shown in figure 1 (d), the oxide single layer exhibited cracks in the film, while in (b) the Cr/Al/Cr film showed very smooth surface morphology without crack after bending test.

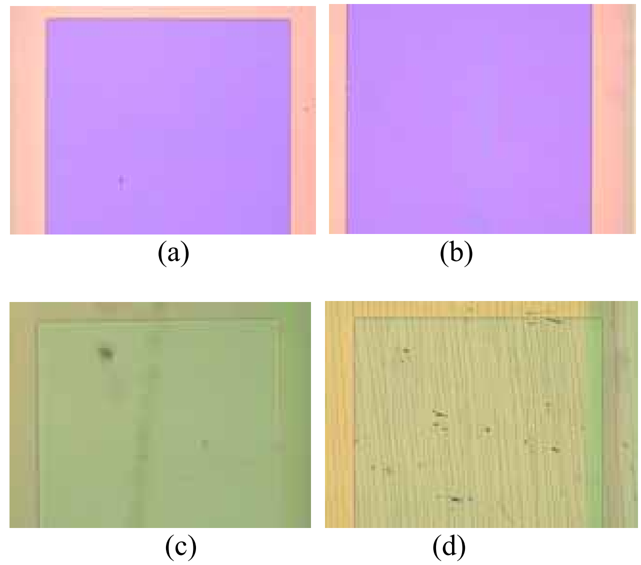

Fig. 2. The anodes on PC substrate before and after bending test. (a) Cr/Al/Cr-before (b) Cr/Al/Cr-after, (c) ITO-before and (d) ITO-after.

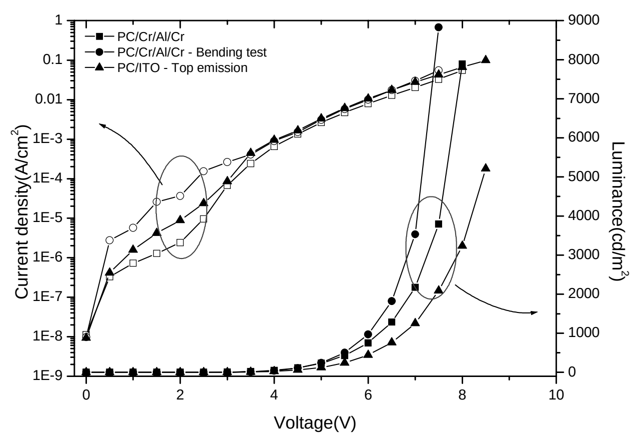

Fig. 3. *J-V-L* characteristics of TEOLEDs on PC films.

Figure 3 shows the current density - voltage – luminance (*J-V-L*) characteristics of the TEOLEDs. The turn-on voltage is about 3V, which is worse than conventional device with glass/ITO anode device. We believe that the high leakage current might be related to the surface characteristics of the Cr/Al/Cr anode and fabrication optimization is under investigation to reduce leakage current. The low luminance of the TEOLED on PC film might be explained by substrate damage due to joule heat during the device operation in high current density region. The device on the PC film has lower voltage for the same emission intensity. The TEOLED exhibited a reasonable luminous efficiency of 9.5 cd/A at 1,000 cd/m^2 with PC film on Cr/Al/Cr anode. Moreover, it showed very stable luminescence property even after bending test. Therefore, it is concluded that our triple anode is very compatible with flexible substrate. The (*J-V-L*) result of PC/ITO film with bending test was not shown because of anode crack (shown Fig. 1. (d)).

The maximum luminance and external quantum efficiencies of the Cr/Al/Cr devices without and with bending test were about 45,000 and 4,800 cd/m^2, and 3.4 and 0.8 %, respectively.

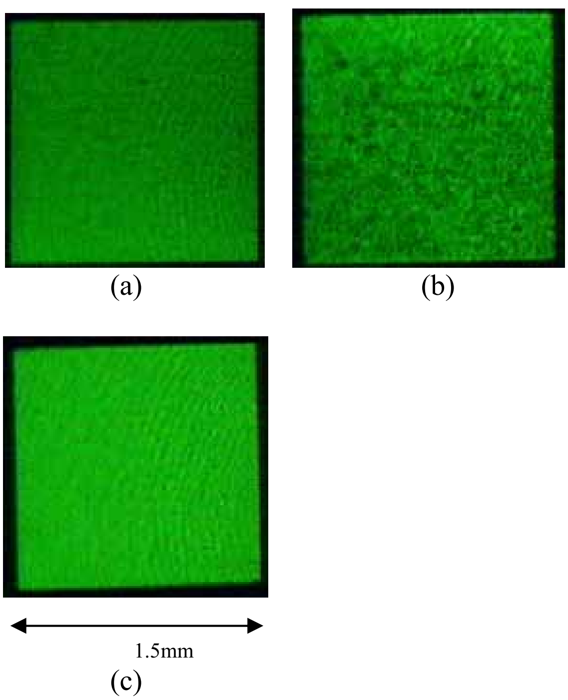

Fig. 4. The emission images of TEOLEDs on PC films before and after bending test (a) Cr/Al/Cr-before (b) Cr/Al/Cr-after and (c) ITO-before.

Figure 4 shows the images of TEOLEDs on PC film. As to the Cr/Al/Cr substrate, an image was observed after the bending test but the ITO substrate was not observed.

Figure 5 shows Electroluminescence (EL) spectra of TEOLEDs on PC films (at 400 μA/cm^2). The EL spectra were similar to each other and the EL maxima of the TEOLEDs on PC films were about 520 nm.

The EL peak appeared at 530 nm in bottom-emission OLED with Alq_3 based on ITO/glass (data not shown). The difference in the emission spectra should be related to the cavity effects of the Cr/Al/Cr layers.

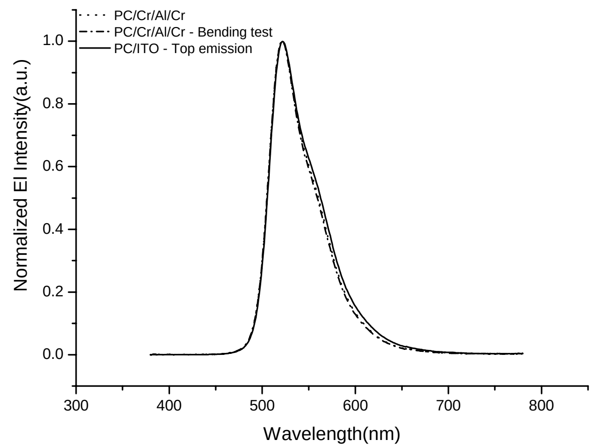

Fig. 5. Electroluminescence spectra of TEOLEDs on PC films.

4. Summary

Cr/Al/Cr of anode has been successfully fabricated on a flexible substrate of PC film. The results demonstrate the feasibility of fabricating flexible display using the triple layer anode on PC film. A TEOLED with a Cr/Al/Cr anode on PC film is a promising candidate for a flexible TEOLED, as it can be bent to a substantial degree without breaking.

5. Acknowledgements

The Korea Ministry of Information and Communications financially supported the accomplishment of this work.

6. References

1. J. Cao, X. Y. Jiang and Z. L. Zhang, App.Phys.Lett.89, 252108 (2006).
2. S. M. Chung, C. S. Hwang, J. I. Lee, S. H. Park,

Y. S. Yang, L. M. Do, and H. Y. Chu, Synthetic Metals 157, 327, (2007)

3. Qin, A. G. Xu, G. L. Ma, G. Z. Ran, Y. P. MQian, B. R. Zhang, W. X. Chen, and S. K. Wu, Appl. Phys. Lett., 85(22), 5406, (2004).
4. J. Cao, X. Y. Jiang, and Z. Zhang, Appl. Phys. Lett., 89, 202108 (2006).
5. S. M. Chung, C.-S. Hwang, J. I. Lee, S. H. Ko. Park, Y. S. Yang, L.-M. Do, and H. Y. Chu, IMID Technical Digest, pp.1374 (2005).