Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 216-217

I-2-6

High performance Fully Transparent Polymer Light-Emitting Devices with Transparent Indium Zinc Oxide Cathode

Chien-Jung Tseng[1], Yung-Hsin Liao[1], Shang-Yu Tsai[1], Chi-Shiau Li[1], Kou-Chen Liu[1]

1. *Institute of Electro-Optical Engineering, Chang Gung University, Taiwan, +886-3-2118800*

1. Introduction

Top emission organic light-emitting devices (TEOLEDs) have caused a considerable interest in recent years and have attracted much attention for as use next-generation displays [1–4]. To enhance the performance of TEOLEDs, it is important to deposit transparent top cathode films, it is desirable to use a low work function metal (ex: Mg, Ag, Ca, etc) or metal alloy (ex: Mg:Ag) as the cathode. However, the devices have given poor light output and low electroluminescent (EL) efficiency for TEOLEDs. Therefore, transparent conducting oxide (TCO) which has high transparency as well as low resistance, and to be able to avoid plasma damage occurring by inserting a buffer layer during the deposition of TCO films. These kinds of materials include indium tin oxides (ITO), indium zinc oxides (IZO), and etc. Currently, ITO is the material which is widely used in the industry. Recently, IZO such as 90 wt % In2O3–10 wt % Zinc oxide (ZnO) and homogeneous In2O3(ZnO)*k* (*k*=2, 3, 4, 5, 6, 7, 9, 11, 13, and15) compounds have attracted significant attention as new candidates for transparent electrodes due to their good conductivity, high optical transparency, excellent surface smoothness, and low deposition temperature[5]. In this letter, we have investigated the enhancement of the fully transparent polymer light-emitting devices (FTPLEDs) using the high transparence IZO cathode. It is shown that FTPLEDs made with the IZO cathodes exhibit higher Luminance and current efficiency as compared with FTPLEDs using the indium-tin-oxide (ITO) cathode.

2. Experiment

Organic layers were deposited by spin coater onto a glass substrate coated with a patterned ITO electrode. A hole injection layer PEDOT:PSS was spin coated onto ITO glass substrate and baked in atmosphere at 120℃ for 15min. Next, the active luminescent polymer film PFO was spin coated onto PEDOT:PSS layer, and baked in glove box at 120℃ for 30 min. Thereafter, the samples were transferred into thermal evaporation chamber that evaporated Ag interlayer (1nm). Then, the IZO cathode was deposited by dc-sputtering 50 W at room temperature (~ 100 nm). The cathode of reference device with ITO was deposited by dc-sputtering 50 W at room temperature (~ 120 nm). All devices were passivated with glass lid and a thin UV-curable resin was applied from a syringe around the edge of the glass adhesively and exposed to UV light 120 seconds.

3. Result and discussion

Figure 1 shows the resistivity of the IZO films which were deposited under different working pressure. We can observe that the curve of resistivity is the minimum under 10 mTorr. The insertion of Fig.1 is the transmittance spectrum of the IZO films deposited under different working pressure. When the working pressure increases up to 10mtorr, the resistivity of the IZO film becomes higher. The reason of the resistivity varying with working pressure is the different kinetic energy of the IZO particles deposited on glass substrate resulted in making change the structure and crystal state of the film. Therefore, the lower resistivity of the IZO film can be required under the appropriate working pressure. The films show a high transparence of over 80% in the visible region at all working pressure. For the FTPLED electrode or flexible substrate application, IZO thin film should use at the low temperature sputtering process. In Fig. 2, the FTPLEDs with the IZO and ITO cathode were examined by measuring the current density–voltage (J–V) characteristics. Both devices show similar electrical behavior, but the turn-on voltage and leakage current of the device with the IZO cathode are slightly superior to the device with ITO cathode. The turn-on voltage decreased from 9.1 to 8.3 V for the device using IZO to replace ITO cathode. The reason is that the resistivity of the IZO film (5.5E-4 Ω-cm) is better the ITO film (2.3E-3 Ω-cm) as our previously reported [6]. For comparison, two I-V curves of FTPLEDs with the IZO and ITO top cathode all devices maintained the same low leakage current density at reverse bias. This indicates that the FTPLEDs fabricated by the dc sputtering method are not affected by plasma damage during IZO sputtering process [7]. The experimental Luminance-voltage (L-V) characteristics measured for two FTPLEDs with IZO and ITO cathode as shown in Fig. 3. It indicates the luminance of the device with IZO cathode is greater than that of the ITO cathode. Figure 3(a) shows the maximum luminance from the top and bottom side of the device with the IZO cathode are 12360 and 12600 cd/m^2, obtained at 0.55 and 0.58 A/cm^2, respectively. The intensity of the light emitted from the top side of the device with IZO cathode is 22% higher than that of the device with ITO cathode at 0.5 A/cm^2. The intensity of the light emitted from the bottom side of the device with IZO cathode is 53% higher than that of the device with ITO cathode at 0.5 A/cm^2. The current efficiency of device with the IZO cathode is higher that the device with the ITO cathode on average as shown in Fig. 3(b). The electroluminescence (EL) spectrum emitted from IZO and ITO transparent cathode of the FTPLEDs are shown in Fig. 4. Two kinds of EL peak at 540 nm are similar, and there is a difference between the full width at half maximum (FWHM) of spectra in them. The EL spectra of devices with IZO and ITO cathode exhibit the FWHM of

Corresponding Author
K.C. Liu, TEL: +886-3-2118800 ext: 3152 E-mail: jacobliu@mail.cgu.edu.tw

66 and 79 nm, respectively. The color purity in device with IZO cathode is better than that in device with ITO cathode from the FWHM observation. We conjectured that the a little strong microcavity effect existed at the Ag/IZO than Ag/ITO interface. However, the out put coupling light intensity was enhanced through IZO cathode. Figure 5 shows work function of the IZO films as a function of work pressure. The work function of IZO film is 4.77 eV under 5 mTorr, which is close to that of conventional ITO film (4.8 eV) by sputtering at room temperature. Due to the work function of the IZO deposition at low temperature is similar to the ITO so, the electron injection barrier height from the cathode to organic materials should be closed. Figure 6 shows that EL intensity function of TCO thickness. The TCO electrode can be regarded as a kind of dielectric layer. In this work, the device is simulated without absorption index of TCOs since it is too little to ignore (Fig. 6), and find that EL intensity is a function of TCO thickness, which varied periodically due to the optical interference [8]. When increasing the refractive index of TCO, the light output coupling become better due to stronger microcavity effect between cathode and anode TCO layer increases. In consequence, proper chosen TCO refractive index and thickness can help the optical performance of the full transparent device with TCO cathode.

4. Conclusion

In summary, we fabricated the FTPLEDs using IZO cathode. The IZO cathode can reduce the turn-on voltage due to lower resistivity at low temperature deposition and increase the electroluminescence due to higher refractive index and stronger microcavity. The luminance increasing 35% on average in our device with the IZO cathode relates to that of the device with ITO cathode. We consider that FTPLEDS can apply windshields and head-up displays in the future.

Reference

[1] G. Gu, V. Bulovic, P. E. Burrows, S. R. Forrest, and M. E. Thompson, Appl. Phys. Lett. 68, (1996) 2606.

[2] L.S. Hung, L.S. Liao, C.S. Lee, S.T. Lee, J. Appl. Phys. 86 (1999) 4607.

[3] S. Han, X. Feng, Z.H. Lu, D. Johnson, R. Wood, Appl. Phys. Lett. 82 (2003) 2715.

[4] G. Parthasarathy, C. Adachi, P.E. Burrows, S.R. Forrest, Appl. Phys. Lett. 76 (2000) 2128.

[5] J.-I. Song, J.-S. Park, H. Kim, Y.-W. Heo, J.-H. Lee, and J.-J. Kim, Appl. Phys. Lett. 90, (2007) 022106.

[6] K. C. Liu et al., Jpn. J. Appl. Phys., Vol. 45, No. 4B (2006) pp. 3742–3745

[7] H. K. Kim, D. G. Kim, K. S. Lee, M. S. Huh, S. H. Jeong, K. I. Kim, and T. Y. Seong: Appl. Phys. Lett. 86 (2005) 183503.

[8] J. M. Ziebarth and M. D. McGehee, J. Appl. Phys. **97**, 064502 (2005)

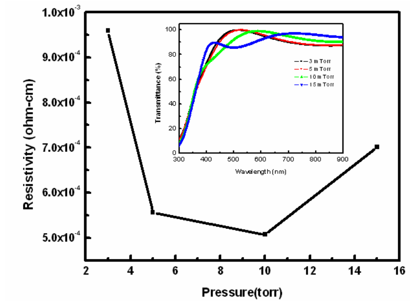

Fig. 1 The resistivity of IZO which were deposited under different working pressure. The insert shows the transmittance of IZO film deposited under different working pressure.

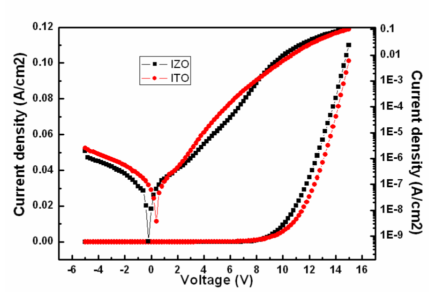

Fig. 2 J–V characteristics of FTPLED deposited with the IZO and ITO cathode.

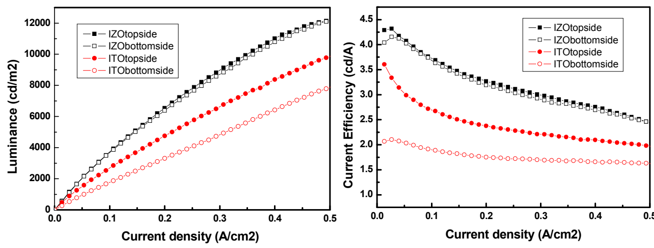

Fig. 3 (a) Luminance and (b) current efficiency vs current density curves with the IZO and ITO cathode.

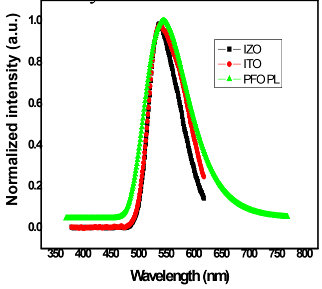

Fig. 4 EL characteristic for FTPLEDs with IZO and ITO cathode and photoluminescence of the PFO film.

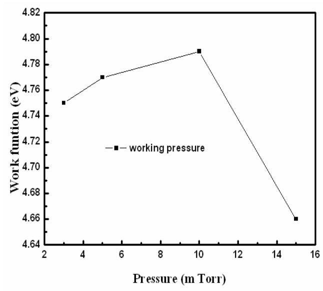

Fig. 5 The work function of the IZO films with different work

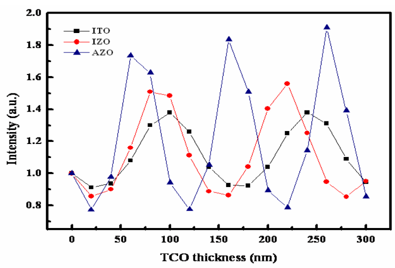

Fig. 6 Simulated EL intensity of the device with ITO (refractive index = 1.9), IZO (n = 2.2), and AZO (n = 2.38) cathodes by different thickness.