Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Transparent White OLEDs Using Ca-Ag Cathode

Chan Jae Lee [a], Jeong In Han [a] & Dae-Gyu Moon [b]

[a] Information Display Research Center, Korea Electronics Technology Institute, Gyunggi, Korea

[b] Department of Materials Engineering, Soon Chun Hyang University, Asan Chungcheongnam, Korea

Version of record first published: 31 Jan 2007

To cite this article: Chan Jae Lee, Jeong In Han & Dae-Gyu Moon (2006): Transparent White OLEDs Using Ca-Ag Cathode, Molecular Crystals and Liquid Crystals, 459:1, 75/[355]-84/[364]

To link to this article: http://dx.doi.org/10.1080/15421400600932264

Mol. Cryst. Liq. Cryst., Vol. 459, pp. 75/[355]–84/[364], 2006

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400600932264

Taylor & Francis
Taylor & Francis Group

Transparent White OLEDs Using Ca-Ag Cathode

Chan Jae Lee
Jeong In Han
Information Display Research Center, Korea Electronics Technology Institute, Gyunggi, Korea

Dae-Gyu Moon
Department of Materials Engineering, Soon Chun Hyang University, Asan Chungcheongnam, Korea

In this paper, we realized a transparent white light emitting device (WOLED) using a single blue emitting layer DPVBi doped with DCJTB. Color turning was done by controlling the thickness of DCJTB doped in DPVBi layer. Transparent electrodes were adapted ITO as anode and Ca-Ag thin layer as cathode. We fabricated transparent WOLED having good color properties, (0.33, 0.30) viewed through Ca-Ag cathode side and (0.36, 0.34) viewed through the ITO anode side, respectively.

Keywords: DCJTB; DPVBi; transparent cathode; white organic light emitting device (WOLED)

INTRODUCTION

White organic light emitting diodes (WOLED) have attracted special attentions owing to their potential applications to realize full color display with high resolution. Three primary colors, red, green and blue, were obtained by using color filters. This approach has advantage that there is no need of fine shadow mask [1,2]. Recently white OLEDs have attracted special interest for a host of potential applications in automobile, traffic information signs, displays and general illumination. Transparent OLED that is 70% transparent when turn off may be integrated into car windshields, architectural windows, and eyewear [3–6].

Address correspondence to Chan-Jae Lee, Information Display Research Center, Korea Electronics Technology Institute, #68 Yatap, Bundang, Seongnam, Gyonggi 463-816, Korea (ROK). E-mail: chanjael@keti.re.kr

To realize white OLED, various structures were suggested by researchers [7–9]. The color was tuned to white by controlling both the thickness of the blocking layer as well as the concentration of dopants. The simple structure, composed with the single emitting layer, used polymer as host and dopant [10]. The other suggested method was to have a stack of two or three emitting layers. In this structure, to emit different color at the each emitting layer, region and degree of recombination was controlled by a carrier blocking layer and doping concentration.

In this work, we report the fabrication of white light emitting device based on the blue and red emission originating from the single emitting layer, DPVBi:DCJTB. To realize the transparent OLED, we adapted two transparent electrodes, ITO as anode and Ca-Ag as cathode. In earlier work, we developed a transparent metal cathode, Ca-Ag which has a high transmittance and low electrical resistance [11]. White color is turned by controlling the thickness of doped layer, DPVBi:DCJTB.

EXPERIMENTAL

Figure 1 shows the structures of fabricated devices used in this work. For transparent white organic light emitting device, two transparent electrodes, ITO as anode and Ca-Ag as cathode were used. Commercially obtained ITO coated glass (SNP) was used in the device fabrication. The anode, ITO was patterned by photolithography and wet etching processes. The organic and metal cathode layers were deposited sequentially with shadow mask by thermal evaporation in a back ground pressure of 10^{-7} Torr and with a deposition rate of 1-2 Å/s. WOLED was composed ITO, 4,4′,4″-tris[2-naphthyl(phenyl)amino] triphenylamine (2-TNATA), 4,4-bis[N-(1-naphtyl)-N-phenyl-amino]biphenyl (α-NPD), 4,4-bis(2,2-diphenylvinyl)-1,1-biphenyl(DPVBi):4-(dicyano-methylene)-2-tert-butyl-6(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran(DCJTB)(0.1%),), tris-(8-hydroxyquinoline) aluminum (Alq3), 2,9-dimethyl-4,7 diphenyl-1,10-phenanthroline (BCP) and Ca-Ag. The DCJTB doped DPVBi layer acts as a red and blue-emitting as well as color tuning layer. The thickness of host emitting layer, DPVBi was 350 Å. DCJTB was doped up to certain thickness in host layer and later again DPVBi was deposited on the top of doped layer. The chromaticity of white emission can be tuned by adjusting thickness of DPVBi host doped with DCJTB. As Ca is extremely sensitive to ambient, the Ag protective film has been deposited on the top of the Ca layer in the same chamber without breaking the vacuum, sequentially. Fabricated devices were encapsulated with glass cap. All the devices have the emitting area of $0.4 \times 0.6\,\text{mm}^2$.

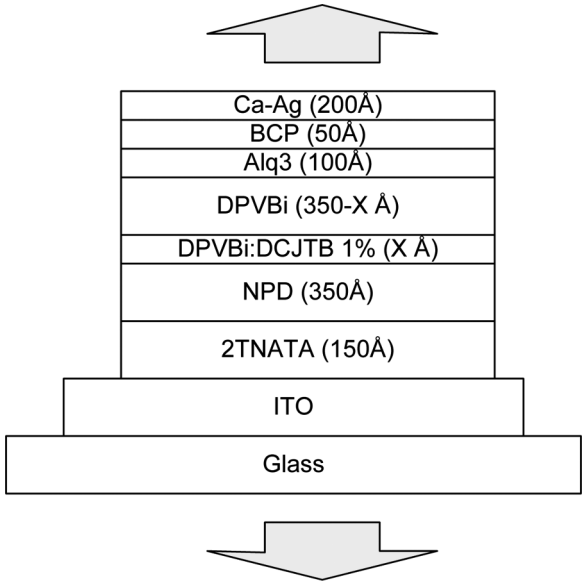

FIGURE 1 The device structure of white transparent OLED.

A spectroradiometer (Minolta CS1000) was employed for measurements of the electroluminence spectrum and the Commission Internationale de L'Eclaorage (CIEx,y). Current-Voltage (I-V) characteristics were measured with an experimental set-up consisting of a Keithley 2400 source meter with calibrated photodiode. Measurements and data acquisition were controlled by National Instrument's LabVIEW software.

RESULTS AND DISCUSSION

Figure 2 shows optical properties of ITO anode and Ca-Ag cathode. It was measured with glass as the reference. Deposited Ca and Ag have thickness of 10 nm each. Ca-Ag cathode has a relatively high transmittance over 70%, although ITO has better transmittance than Ca-Ag, as shown in Figure 2.

The high transparency of Ca-Ag cathode may be explained on the basis of the knowledge of the penetration of visible light through the metal thin films. Although it is well know that the metal has a high reflectance at its surface, as the thickness of a metal layer is thinner, metal layer become transparent. This limited thickness is explained as the optical skin depth. For most of metals, the skin depth is 10 nm approximately for the visible light range [12]. The Ca layer (10 nm) was deposited in a background pressure $\approx 2 \times 10^{-6}$ Torr with a

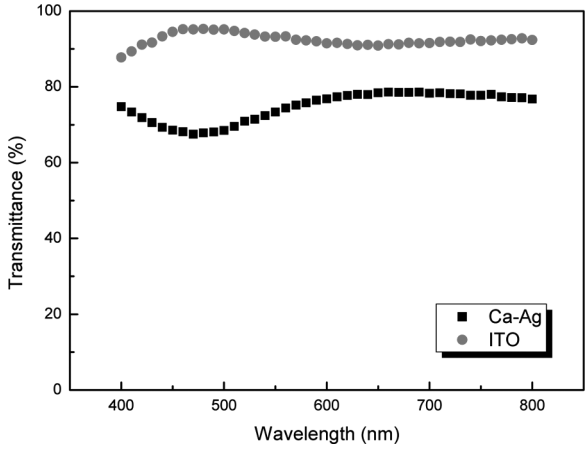

FIGURE 2 Transmittance curve of ITO and Ca-Ag.

deposition rate ≈1–2 Å/s. Later, the Ag protective metal layer (10 nm) was deposited on the top of the Ca layer in the same background pressure with a same deposition rate as that of Ca metal. It was reported earlier that during Ca deposition at the background pressure 10^{-8} to 10^{-6} mbar with a deposition rate ≈4 Å/s, the partially oxidized calcium can be produced in the Ca layer [13]. As the background pressure of 2×10^{-6} Torr during the deposition of Ca is in this range, the partially oxidized Ca film is believed to be formed. The transparency of Ca-Ag cathode is significantly improved by the formation of a thin CaO layer (refractive index, $n = 1.830$) between the partially oxidized-Ca and Ag ($n = 1.2$) layers [14].

White OLEDs were fabricated by controlling the thickness of doped layer. Total thickness of an emitting layer was fixed to 350 Å and DPVBi layer doped with DCJTB was controlled as the definite thickness, X = 120, 150, 160, 170 and 250 Å with a fixed doping concentration of 0.1%. Normalized EL spectra of devices were represented in Figure 3. It is observed that the intensity of blue peak increased with the decrease with thickness of DPVBi:DCJTB. But, in spite of the different doped thickness, X, devices have two main peaks, blue and red. The white balance of device was controlled by the degree of blue and red peaks. Energy transfer from DPVBi to DCJTB did not happen completely by limited thickness of doped emitting layer. As DPVBi:DCJTB layer becomes thinner, the ratio of position occurred recombination was larger in only DPVBi layer than in DPVBi:DCJTB.

Generated light was transmitted though both electrodes, ITO and Ca-Ag. So the transmitted light shows a little difference in the points

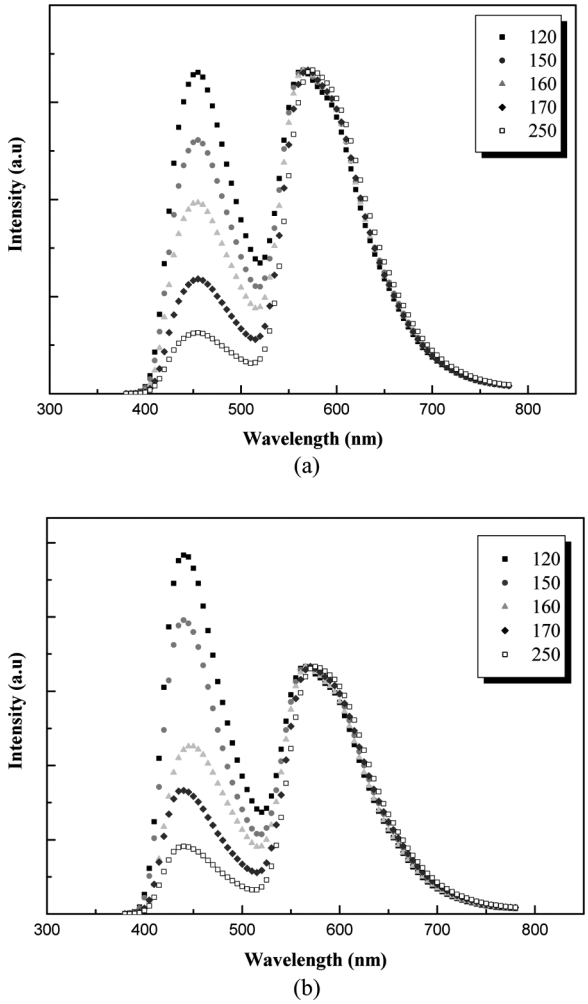

FIGURE 3 EL emission spectra of device with various doped thickness, X (a) through ITO anode, (b) through Ca-Ag cathode.

of spectra and brightness. Blue spectra through Ca-Ag were more intensive than through ITO. Although both lights through ITO and Ca-Ag have a similar wavelength, about 575 nm, blue light obtained from the ITO side peaks at 455 nm whereas peaks at the 440 nm when observed from the Ca-Ag cathode side. Moreover, in the case of $X = 120$, the intensity of light through ITO in the blue light has similar with that of red light, but the intensity of light through

TABLE 1 CIE Coordination and Brightness as DPVBi:DCJTB Thickness, X at 10 V

Sample	View side	CIE (x,y)	Brightness (cd/m2)
X = 120	ITO	0.30,0.32	2202
	Ca-Ag	0.33,0.28	719
X = 150	ITO	0.36,0.34	3813
	Ca-Ag	0.33,0.30	1216
X = 160	ITO	0.38,0.36	1054
	Ca-Ag	0.36,0.34	866
X = 170	ITO	0.42,0.40	1314
	Ca-Ag	0.40,0.37	927
X = 250	ITO	0.47,0.42	1314
	Ca-Ag	0.45,0.40	439

Ca-Ag in the blue light was much higher than that of the red light. This sensitivity in the blue light was due to nonuniform optical transmittance of Ca-Ag in visible range.

Table 1 shows CIE Coordination and brightness each WOLED as function of DBVBi:DCJTB thickness and electrode through which light transmitted. When X was 150 Å, color was nearest to white. Brightness through ITO was higher about three times than Ca-Ag. By considering the higher transmittance of ITO about 90% and that of Ca-Ag about 70%, lower brightness of light through Ca-Ag was as expected. These phenomena were assumed by the much higher reflectivity of Ca-Ag about 15–18% in the visible range than that of ITO [15]. Emitted light progressed to both side, these light either transmitted trough each electrode or reflected to the surface of electrode. Some of arrived light at the Ca-Ag electrode was reflected back at the cathode as the degree of reflectance of the cathode and then progress towards the anode. This light was transmitted out from the device or reflected at the anode as the degree of reflectance of the anode and is directed towards the cathode. Because the reflectance of Ca-Ag was about twice as high as of ITO, the degree of reflected light at the surface of Ca-Ag was much than the degree at the surface of ITO. So brightness of the light measured through ITO was much higher than through Ca-Ag cathode.

Figure 4 shows the band diagram of the fabricated white OLED structure. As shown in the diagram, excitation of DPVBi was used to emit blue light and partially transfer energy to DCJTB. In the case of red emission, the excitation has two paths. One was energy transfer from DPVBi and the other was direct recombination to DCJTB [16]. Because our device was controlled by the thickness of DCJTB, as the

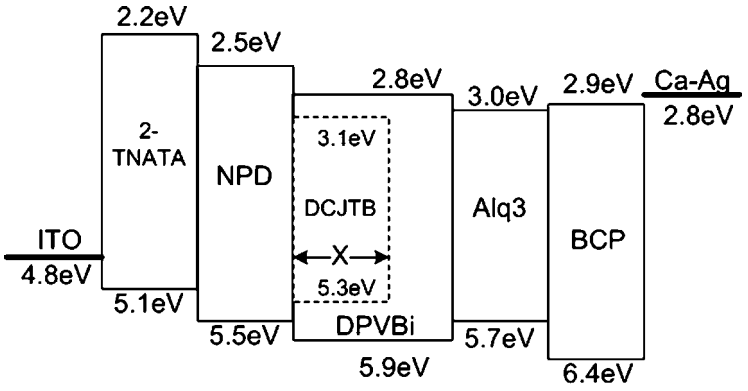

FIGURE 4 Schematic energy level diagram of fabricated device.

doped thickness increased, recombination for emission was mainly occurred to DCJTB site and intensity of red peak was increased. But in our device, doping concentration was not sufficient to transfer from DPVBi to DCJTB, so recombination in the DPVBi was largely used to make blue emission.

To realize white OLED, some researchers suggested multi emitting layers and carrier blocking layer. Here we have was designed the device with single emitting layer without any charge carrier blocking layer. Generally the multi-emitting structure with a charge carrier blocking layer device has the problem that spectrum and CIE coordination change with the increase of driving current. However, our device which has the single emitting layer, DPVBi and red spectrum for white is realized by partial energy transfer from DPVBi. Therefore, because carriers in this structure are not accumulated at the each color emission layer, white balance has negligible change as the increase of the driving voltage as shown in Table 2. Small color change

TABLE 2 CIE Coordination Index as Driving Voltage at X = 150

Driving Voltage, Current density	View side	CIE (x,y)	Brightness (cd/m2)
8 V, 18 mA/cm^2	ITO	0.3606, 0.3438	577
	Ca-Ag	0.3307,0.3068	408
10 V, 59 mA/cm^2	ITO	0.3618,0.3405	3813
	Ca-Ag	0.3310, 0.3025	1216
12 V, 120 mA/cm^2	ITO	0.3625, 0.3401	3287
	Ca-Ag	0.3605, 0.3019	2300

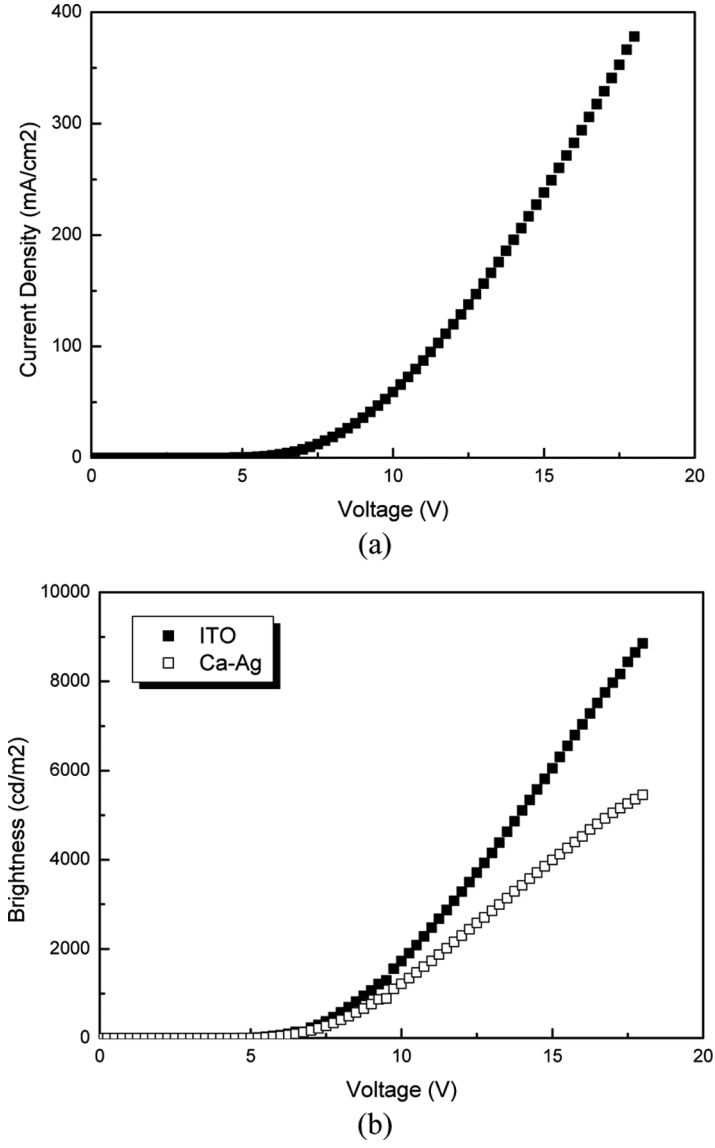

FIGURE 5 Electrical characteristic curve of device with X = 150: (a) voltage-Current density; (b) voltage-brightness.

with the increase of driving voltage may be assigned to fast induced recombination in the DPVBi was faster than that of the DCJTB by the alignment of HOMO and LUMO with neighbor layer.

Figure 5 shows the current density-voltage and brightness-voltage characteristics curve of white transparent OLED with X = 150. The turn-on voltage was about 5.5 V. The CIE coordinates at 10 V were (0.36, 0.34) obtained through ITO electrode and (0.33, 0.30) through Ca-Ag electrode, respectively. Maximum efficiency was 3.1 cd/A at 8 V, 557 cd/m^2 through ITO and 2.2 cd/A at 8 V 408 cd/m^2 through Ca-Ag.

CONCLUSIONS

We have demonstrated a white transparent OLED with two transparent electrode, ITO as anode and Ca-Ag as cathode. Ca-Ag structure is a high transparent material and suitable as cathode for OLED. White light is realized by using two colors, blue and red. Fabricated device has a single emitting layer DPVBi and only definite doped layer with DCJTB in the DPVBi layer. The thickness of DCJTB doped in DPVBi was controlled between 120 Å and 250 Å, and doping concentration was fixed to 0.1%. These are partial energy transfer form DPVBi to DCJTB due to insufficient doping concentration and the definite thickness. When the thickness of DCJTB doped in DPVBi is 150 Å, I-V-L characteristics and white balance are optimum. The brightness and CIE coordinates at 10 V are 3813 cd/m^2, (0.36, 0.34) through ITO electrode and 1216 cd/m^2, (0.33, 0.30) through Ca-Ag electrode, respectively. In conclusion, we have demonstrated efficient white light emission from a single layer by controlling the thickness of doped layer.

REFERENCES

[1] Jordan, R. H., Dodabalapur, A., & Strukeji, M. (1996). *Appl. Phys. Lett.*, *68*, 1192.
[2] Mattoussi, H., Murata, H., Merritt, C. D., Lizumi, Y., Kido, J., & Kafafi, Z. H. (1999). *J. Appl. Phys.*, *86*, 2642.
[3] Bulovic, V., Gu, G., Burrows, P. E., Forrest, S. R., & Thompson, M. E. (1996). *Nature*, *380*, 29.
[4] Gu, G., Bulovic, V., Burrows, P. E., Forrest, S. R., & Thompson, M. E. (1996). *Appl. Phys. Lett.*, *68*, 2606.
[5] Antikainen, M., Haaranen, J., Honkala, J., & Lahohen, M. (2000). *SID 00 Digest*, 885.
[6] Tsuruoka, Y., Hieda, S., Tanaka, S., & Takahashi, H. (2003). *SID 03 Digest*, 860.
[7] Kido, J., Kimura, M., & Nagai, K. (1995). *Science*, *267*, 1332.
[8] Forrest, S. R., Burrows, P. E., & Shen, Z. (1997). *Synth. Met*, *91*, 9.
[9] Jiang, X. Y., Zhang, Z. L., & Zhao, W. M. (2000). *J. Phys. D; Appl. Phys.*, *33*, 742.
[10] Granstrom, M. & Inganas, O. (1996). *Appl. Phys. Lett.*, *68*, 147.
[11] Lee, C. J., Pode, R. B., Moon, D. G., Han, J. I., Park, N. H., Baek, S. H., & Ju, S. S. (2004). *phys. stat. sol.(a)*, *5*, 201.

[12] Scalora, M., Bloemer, M. J., Pethel, A. S., Dowling, J. P., Bowden, C. M., & Manka, A. S. (1998). *J. Appl. Phys.*, *83*, 2377.
[13] Andersson, G., de Jong, M. P., Janssen, F. J. J., Sturn, J. M., van I Jzendoorn, L. J., Denier van der Gon, A. W., de Voigt, M. J. A., & Brongersma, H. H. (2001). *J. Appl. Phys.*, *90*, 1376.
[14] Lee, C. J., Pode, R. B., Moon, D. G., & Han, J. I. (2004). *Thin Solid Films*, *467*, 201.
[15] Lee, C. J., Pode, R. B., Moon, D. G., & Han, J. I. (2004). *Proc. of SPIE*, *5464*, 306.
[16] Zheng, X. Y., Zhu, W. Q., Wu, Y. Z., Jiang, X. Y., Sun, R. G., Zhang, Z. L., & Xu, S. H. (2003). *Displays*, *24*, 121.