Microcavity-enhanced White OLED for efficient lighting application

Byung Doo Chin*, Jae Kyeong Kim
Optoelectronic Mater. Research Center, Korea Institute of Science & Technology
P.O.Box 131, Cheongryang, Seoul, 130-650, Korea
***Phone: +82-42-958-5330, E-mail: bdchin@kist.re.kr**

Abstract

In this work, we fabricated efficient white organic light emitting device (WOLED) by the stack of complementary fluorescent dye-doped layers, Effect of dye-doping ratio and thickness of each layers on WOLED efficiency and emission spectrum was investigated. Moreover, out-coupling efficiency enhancement using microlens array was analyzed for bottom and top-emitting device architecture, leading to higher light extraction properties.

1. Introduction

White organic light emitting devices (WOLEDs) are of considerable interest both for simple and efficient backlights of flat-panel display and next generation light illumination devices. White light emission can be obtained from multilayer OLED structures in which different layers emit different portions of visible spectrum [1.2], single-layer blends of polymer emitting materials [3,4], hybrid organic/inorganic composite emitters [5.6], and excimers [7]. Although electrophoshorescent dopants employed for WOLED produce high power efficiency with maximum 18lm/W [2,8], requirement of complicated device architecture (insertion of thin layers of hole blocking materials) as well as poor stability of blue electrophosphorescent emitters inhibit their commercial application. Recently, more efficient utilization of both singlet and triplet exciton at multilayerd white OLED was reported [9].

Compared to WOLED with small molecular materials, copolymers containing structural elements for blue, green and red emission in appropriate concentrations were another feasible approach that can be fabricated by simple processes proven for monochrome displays -like spin coating or even screen printing [11]. Although polymeric white emission has advantages such as easily controllable color spectrum, suitability for large area coating, and feasibility on a flexible application, it has been still suffering from limited efficiency and short device lifetime.

Indeed, stacking of molecular light emitting materials (small molecule) for WOLED fabrication is rather complicated than solution-processed polymeric or dye-doped WOLED. In case of WOLED with fluorescent small molecular dopant, management of doping ratio less than 0.5 ~ 3% within thin layer of 5~6nm is required at continuous process. Key design factor of white emission is forming of broad recombination region of holes and electrons (exciton distribution over the position of thin multilayers containing red, green, and blue emitters), which can be possible at diluted doping concentration but lowering the dopant concentration generally resulted in the reduction of efficiency and brightness. Due to the advantage of its broadband emission spectrum, WOLED containing three component emitting layers (red, green, blue emission) is competitive for achieving high color rendering index, possibly with replacement of red (sometimes with insertion of green) light emitting layer with phosphorescent materials for higher internal device efficiency [10]

In this work, we have fabricated 2-peak (blue/orange component) and 3-peak (blue/green/orange components) WOLED based on fluorescent dye-doped small molecules. Effects of relative thickness and doping ratio (we found that major control parameter is blue-emitting material's layer thickness) on the electroluminescent spectra and efficiency were investigated. We have further investigated the effectiveness of attached microlens array for each WOLED devices and compared the outcoupling light extraction improvement. Tuning of EL spectrum for balanced white emission at fluorescent/phosphorescent layered device structure was shortly illustrated.

2. Results

Materials and Fabrication of Devices

Organic layer of N,N'-diphenyl-N,N'-bis (1-naphthyl)-(1,1'-biphenyl)-4,4'-diamine (NPB, 50nm) hole transport layer (HTL) was vacuum-deposited at $2x10^{-7}$

Torr onto UV-O_3 treated 150nm-thick indium tin oxide (ITO) substrates. 2,2',7,7'-tetrakis-(2,2' -diphenyl-vinyl)- spiro-9,9'-bifluorene (spiro-DPVBi : host) doped with 1.5% 9,10-Di(naphtha-2-yl)anthracene (ADN) were evaporated as light-blue emitting layer (6~30nm). Onto this layer, same host material was deposited with yellow-orange emitter (rubrene, 25~30nm with 2% concentration). Then, 20nm electron transport layer of tris(8-hydroxyquinoline)-aluminum (Alq3) was deposited followed by LiF/Al cathode. The thickness was measured with a calibrated oscillating crystal monitor and encapsulation using calcium oxide getter inside was performed in a nitrogen glove box. Materials and device architecture for fluorescent complementary light emitting structures were shown in Fig. 1.

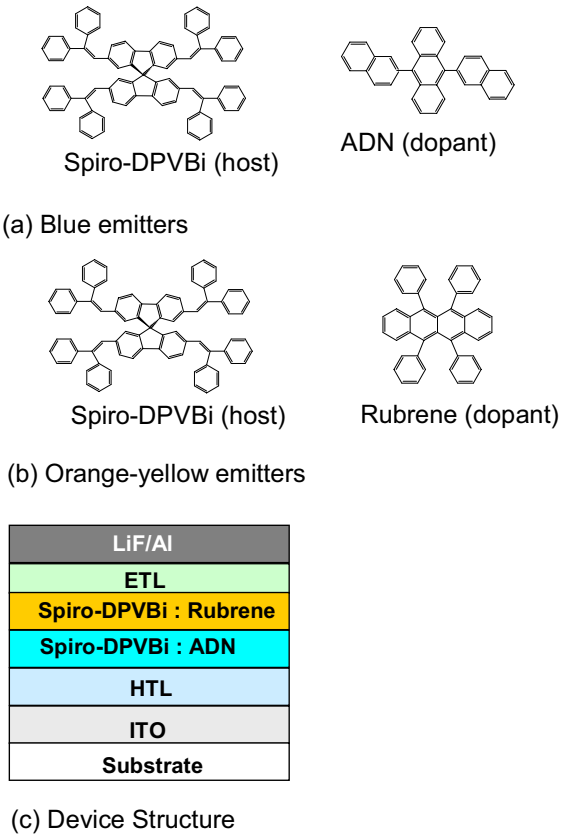

Fig. 1. Chemical structure of materials (complementary emission layers of WOLED) and configuration of 2-layer WOLED devices used in this study.

Device Performances : Efficiency, Spectrum, and CIE

The spectrum data of WOLED with fluorescent blue and orange dual emission layers devices are shown in Fig. 2. Obviously, these devices emitted blue fluorescent from (spiro-DPVBi:BCzBVi, 1.5%) and orange fluorescent light (spiro-DPVBi:rubrene, 2%) simultaneously, suggesting that excitons formed at spiro-DPVBi/Alq3 and NPB/ spiro-DPVBi interfaces are effectively utilized within this dual layer. When the relative thickness of blue and orange emitting layer is varied, WOLED's electroluminescent spectra undergo significant change. Starting from 5nm-thick blue emitting layer, intensity of ~580nm rubrene tends to decrease as increasing the relative thickness of blue emitting zone (showing 470nm peak emission).

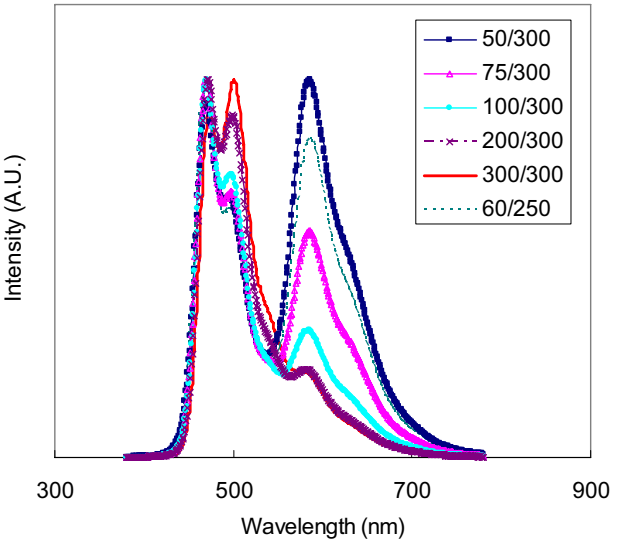

Fig.2 Variation in the electroluminescent spectra with layer thickness of spiro-DPVBi:BCzVBi and spiro-DPVBi:rubrene (at 10mA/cm^2)

Fig. 3 shows the current density/voltage properties and voltage-luminous efficiency (cd/A) properties of the WOLED devices having fluorescent blue and orange dual emission layers, varying the layer thickness of blue emitting region. It is clear that increase of thickness for blue emitter resulted in the peak efficiency (>10cd/A). However, charge injection at thicker emitting layer condition seems to be inferior than 6nm blue layer, showing the reduced current density and brightness. Since same host molecule was used both for blue and red emission, white broadband spectra of each devices were independent of the operating voltage within the experimental window (3~15V). From the brightness-voltage data of

WOLED (not shown in Fig.3), turn-on voltage of 6nm/25nm (blue/orange) device was <3.0V, which increases up to 3.5eV for 7.5nm/30nm and 10nm/3nm emitting layer thicknesses. For device with 7.5/30nm (blue/orange) thickness, 10.1cd/A (4.05lm/W) efficiency at 7.8V with balanced white emission (0.32, 0.34) of Commission Internationale de l'Eclairage (CIE) 1931 coordinate. Effect of blue emitting layer thickness on the variation of CIE 1931 coordinate was shown at Fig.4.

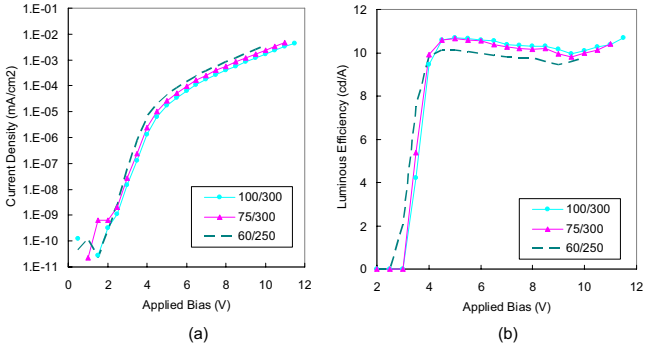

Fig.3. Current density-voltage characteristics (a) and voltage-luminous efficiency characteristics (b) of WOLED with fluorescent blue/orange emission layers

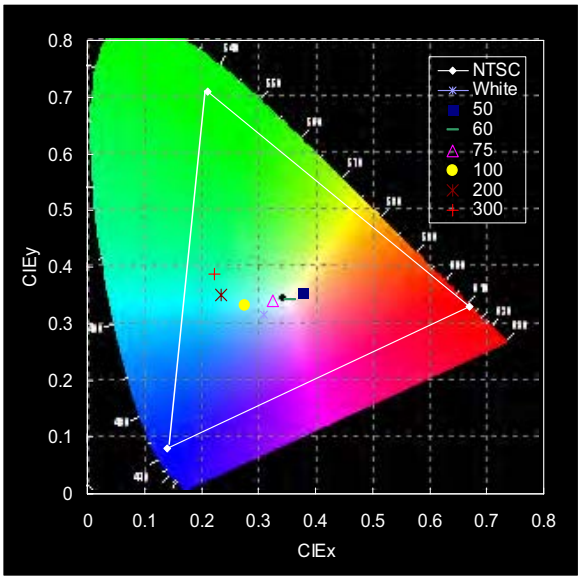

Fig. 4. Evolution of CIE 1931 coordinates of the WOLED with fluorescent blue/orange emission layers (with variation of blue emitting layer's thickness). The triangle lines are NTSC and point of white indicates (0.33, 0,33)

Although WOLED with fluorescent blue/orange dual layer showed acceptable white electroluminescent spectrum and CIE1931 color coordinate ranging from 0.28<x<0.35 and 0.30<y<0.40, it is still required to enhance the emission spectrum intensity in the 450 ~ 550nm wavelength region, which will be essential for white broadband emission spectrum. For the layered fluorescent emitters of blue/green/red(orange) using same host material, emission spectrum and device efficiencies was investigated.

Microcavity/outcoupling

It is reported that factor of 1.2 ~ 1.8 external light extraction intensities can be achievable by using of various outcoupling-enhancement technique [4]. We have attached polydimethylsiloxane (PDMS) microlens array onto the glass substrate of bottom-emission WOLED and surface of semi-transparent cathode. Effects of outcoupling enhancement for both WOLED lighting properties was examined.

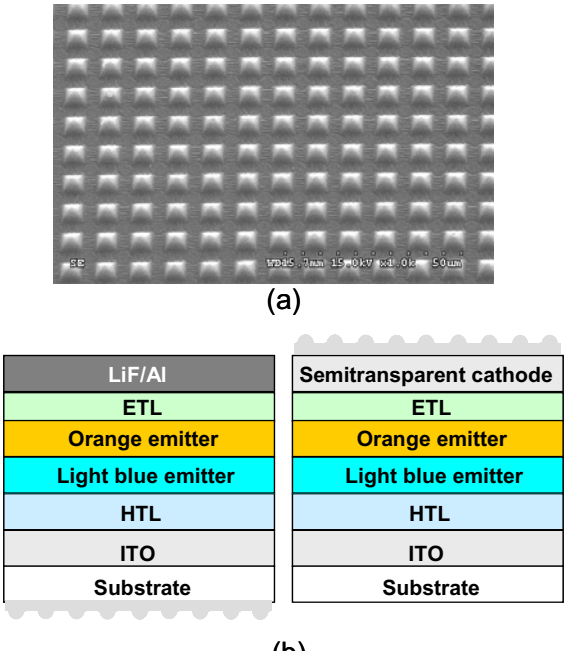

Fig.5. Scanning Electron Microscopy (SEM) image of used ordered microlens for WOLED outcoupling enhancement (a) Scheme of device architecture using microlens array

3. Conclusion

WOLED with emitting layers of stacked small molecules and diluted dopant concentration were considered. Blue and yellow-orange emission from fluorescent host:dopant layers were optimized for

adjusted color spectrum, higher efficiency, and low driving voltage. Insertion of additional green-emitting fluorescent dye-doped layer effectively improved the color reproducible range (broadband white spectrum). We also have shown the effectiveness of simple outcoupling scheme using microlens both for bottom- and top-emission WOLED device structures.

4. Acknowledgements

This research was supported by contract of FA5209-06-0184 AOARD from AFOSR/KIST and grant code #: 05K1501-02300 from 'Center for Nanostructured Materials Technology' under 21th Century Frontier R &D Program' of the Ministry of Science and Technol ogy, Korea.

5. References

[1] X. Jiang, Z. Zhang, W. Zhao, W. Zhu, B. Zhang, S. Xu, J. Phys. D: Appl. Phys., 33 (2000) 473.

[2] B.W. D'Andrade, M. E. Thomson, S.R. Forrest, Adv. Mater., 14 (2002) 147

[3] J. Kido, H. Shionoya, K. Nagai, Appl. Phys. Lett. 67 (1995) 2281.

[4] B.W. D'Andrade, R. J. Holmes, S. R. Forrest, Adv. Mater., 16 (2004) 624

[5] J. Feng, F. Li, W. Gao, S. Liu, Y. Liu, Y. Wang, Appl. Phys. Lett., 78 (2001) 3947.

[6] J. H. Park, J. Y. Kim, B. D. Chin, Y. C. Kim, J. K. Kim, O O. Park, Nanotechnology 15 (2004) 1217

[7] B.W. D'Andrade, J. Brooks, V. Adamovich, M.E. Thomson, S.R. Forrest Adv. Mater., 14(2002) 1032

[8] Y. J. Tung, T. Ngo, M. Hack, J. Brown, N. Koide, Y. Nagara, Y.Kato, H. Ito, "A high efficiency phosphorescent white OLED for LCD backlight and display applications", Society of Information Display (SID2004) Technical Digest, 35, 48-51

[9] Y. Sun, N. C. Giebink, H. Kanno, B. Ma, M. E. Thomson, S.R. Forrest, Nature, 440 (2006) 908

[10] D. Qin, Y. Tao, Appl. Phys. Lett., 86 (2006) 113507

[11] D.Buchhauser, M. Scheffel, W. Rogler, C.Tschamber, K.Heuser, A.Hunze, G. Gieres, D. Henseler, W.Jakowetz, K. Diekmann, A. Winnacker, H.Becker, A. Büsing, A.Falcou, L.Rau, S.Vögele, S. Göttling. "Characteristics of white emitting copolymers for PLED-display", Proc. SPIE 5519 (2004) 70

[12] W, Xie, Y. Zhao, C. Li, S. Liu, Semicond. Sci. Technol. 20 (2005) L57