Improved Light Extraction of Organic Light Emitting Diode With Microcavity structure based on $SiO_2/TiO_2/SIO_2$ Multi 1D Layer

Nam Su Kang [1,2)], Jai-Kyeong Kim[1)], Jai-woong Yoo[1),]

Byeong-Kwon Ju[2)], Byung Doo Chin[1)*]

***Center for Advanced Energy Materials,* Korea Institute of Science and Technology, P.O.BOX 131, Cheongryang, Seoul 130-650, Korea[1)]**

TEL:082-2-958-5330 , E-mail: bdchin@kist.re.kr (Corresponding Author*)*

Display and Nanosystem Laboratory, College of Engineering, Korea University, Seoul 136-713, Korea[2)]

Keywords : OLED, Microcavity, distributed Bragg reflector

Abstract

In this work, we have modeled and fabricated microcavity-enhanced OLED using the 1-dimensional distributed Bragg reflector model (DBR). Results show that simulated spectrum intensity of microcavity OLED increased more than 30% compared to the conventional OLED, by use of DBR with TiO_2 and SiO_2. Spectral change of green and blue emission was expected to give the deeper color. The experimental design and characterization as well as the matching with simulated properties were performed for microcavity OLED for actual application.

1. Introduction

Organic light emitting diode(OLED) are attractive for applications for next generation display device due to their self emission, short response time, a wide viewing angle, and better color reproduction, etc. In addition to the significant progress in the device structure of organic multi-layers, optical design of OLED has received a great deal of attention as a means of tailoring its external light emitting properties, since almost 80% of the generated light of OLED is lost due to wave-guiding and total internal reflection in the glass substrates. Recently, various submicro- and nano-patterned (or layered) structures are applied to enhance the light extraction efficiency. Two dimensional photonic crystals enhance the out-coupling of light along the surface normal, as well as use of reflecting surfaces or distributed Bragg reflectors [1,2]. It has been found that the external quantum efficiency and the spectral characteristic significantly depend on the OLED architecture, in particular on the layer thicknesses as a consequence of optical interference effects [3]. A stronger microcavity effect in the recent top-emitting OLEDs is a good example of optimized device structure for practical application. Consequently, many efforts have been performed in order to improve the light out-coupling efficiency of OLEDs both for bottom-emitting and top-emitting devices. Much attention has been paid to optical model for increased light extraction from the inside OLED structure by dielectric mirrors, metal mirrors and organic cavity structure [4~7].

2. Experimental

PEDOT:PSS (Baytron P TP Al 4083) was used after filtering through a 0.45-μm PTFE filter. The interfacial layer material employed was poly(9,9'-dioctylfluorene-co-bis-N,N'-(4-thoxycarbonylphenyl)-bis-N,N'-phenyl-benzidine(BFEC). For emission layer, 4,4'-bis(9-carbazolyl)-2,2'-biphenyl(CBP) and Tris(8-hydoroxyquinoline)($Ir(ppy)_3$) was deposited with weight ratio of 1: 0.0.7. Bis(8-bydroxyquinaldine) aluminum biphenoxide (BAlq) and tris-(8-hydroxy quinoline)aluminum(Alq_3) were used as HBL (Hole blocking Layer) and ETL (Electron transport layer), respectively.

ITO substrates were cleaned by ultra-sonication in deionized water and isopropanol (IPA), acetone and finally subjected to UV-O_3 treatment for 15 minutes. Onto this substrate, a 35-nm-thick layer of PEDOT:PSS was spin-coated, followed by drying at 200℃ for 5 minutes. Then, a thin layer of BFEC was spin-coated onto the PEDOT:PSS layer as an interfacial layer. This was achieved by spin coating a 15-nm thick layer onto the PEDOT:PSS from a

solution of BFEC in anhydrous toluene, followed by baking at 250℃ for 5 min in a nitrogen environment.

Layer of organic materials and cathode were EML 30 nm/Balq 5 nm/Alq3 20 nm/LiF 0.5 nm/Al 150 nm. These layers were thermally deposited at less than 5×10^{-7} Torr. Dielectic materials for cavity were doposited at pressure less than 2×10^{-6} Torr by use of electron beam vaper deposition evaporator.

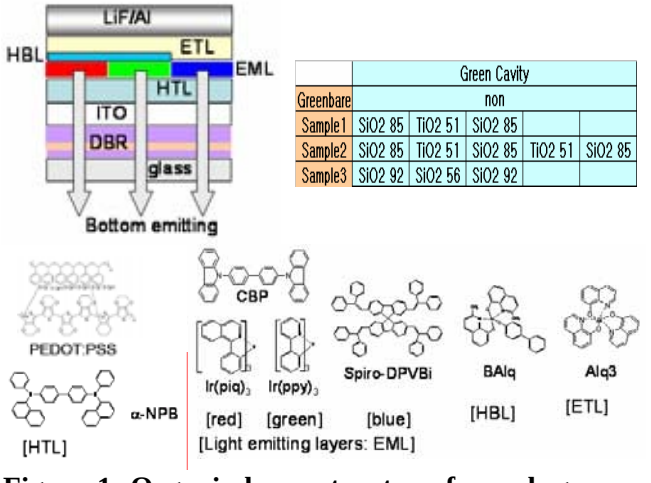
The thickness of the organic layers and cavity layer was measured with an alphastep surface profiler P-10 (Tencor). Electroluminescence characteristics were measured using a Keithley 2400 source meter and CS-1000 Spectrascan calorimeter.

3. Results and discussion

In this paper, we performed analytical and experimental approach to improve the light out-coupling efficiency of conventional bottom-emitting and transparent-type OLED device by use of nanostructured dielectric mirrors (Bragg reflectors). After suitable OLED model was selected, we defined the microcavity structures. The cavity length is expressed by

$$L(\lambda)=\frac{\lambda}{2}\left(\frac{n_{eff}}{\Delta n}\right)+\sum_j n_j L_j+\left|\frac{\phi_m}{4\pi}\lambda\right| \qquad (1.1)$$

where n_{eff} and Δn denote the effective refractive index of the DBR and the refractive index difference between SiO2 and TiO2.



	Green Cavity				
Greenbare	non				
Sample1	SiO2 85	TiO2 51	SiO2 85		
Sample2	SiO2 85	TiO2 51	SiO2 85	TiO2 51	SiO2 85
Sample3	SiO2 92	SiO2 56	SiO2 92		

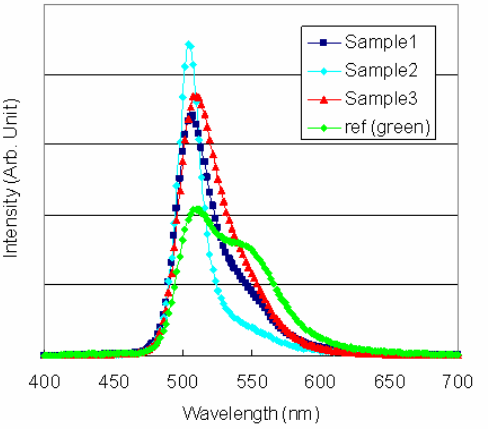
Figure 1. Organic layer structure for red, green, blue light emitting devices and DBR cavity structure for green.

n_j and L_j are refractive index and thickness of the organic and indium tin oxide(ITO) layers, respectively. ϕ_m is the phase shift at the metal cathode express by [8~10]

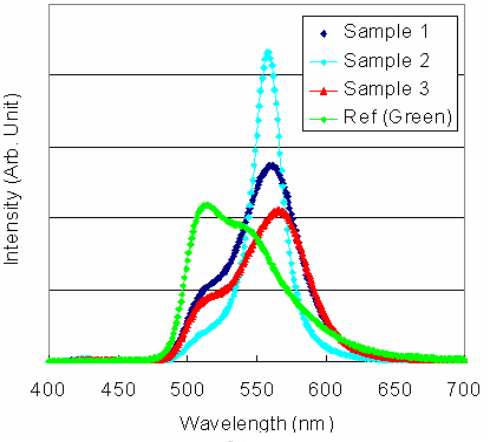
$$\phi_m=\tan^{-1}\left(\frac{2n_sK_m}{n_s^2-n_m^2-k_m^2}\right) \qquad (1.2)$$

where n_s is the refractive index of the organic layer in contact with the metal cathode, and n_m and k_m are the real and imaginary parts of the refractive index of the metal cathode, respectively.

Optimum thickness of the cavity was determined using cavity equation. Device structure, employed materials, and design of green cavity OLED were shown in figure 1. For these cavity structures, simulated and experimental light emitting spectrum was illustrated in Figure 2.



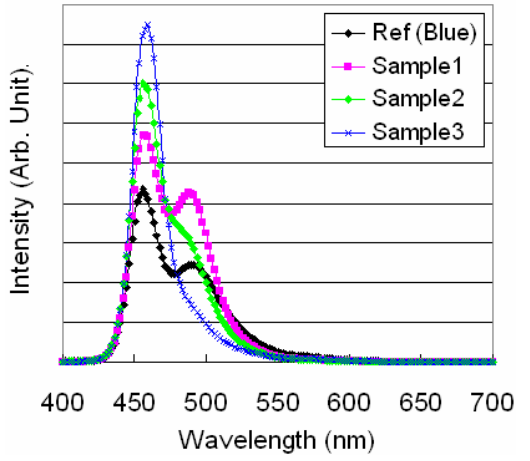
(a)



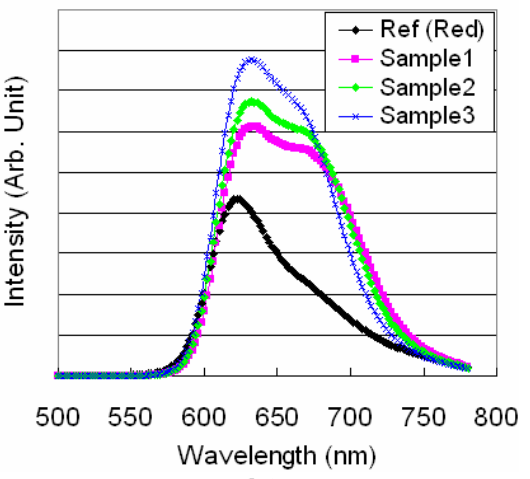
(b)

Figure 2. Light emitting spectra of green microcavity-enhanced OLED in comparison to the non-cavity bottom emission green OLED based on electrophosphorescent material (a) simulated (b) experimental results

Microcavity structure induced the increase of light emitting intensity for 30~100% by simulation compared to conventional OLED structure. The discrepancy between the simulated and experimental results at green was caused by the increase of ITO thickness from 100 nm (design for simulation) to 130 nm (in order to ensure acceptable resistivity as OLED anode) and other miscellaneous factors, which will be compensated by additional of DBR structure design and experiments



(a)



(b)

Figure 3. Spectral characteristics of red phosphorescent OLED (a) and blue fluorescent OLED (b) simulated results

Figure 3 shows the simulated spectra of red and blue microcavity structure. We could expect the deeper blue emission by the evolution of microcavity-induced narrow blue emission peak. This simulation result shows that EL intensity was generally improved more than 30%.

4. Summary

In this study, we have investigated the precisely-controlled microcavity structure using SiO_2 and TiO_2 multi-layers between the ITO layer and glass substrate resulting in the increased light extraction at least to the perpendicular direction of the substrate plane. Experimental data in the device using the designed microcavity structure was investigated in a close relation with the simulated properties.

5. Acknowledgements

This work was supported by contract of FA5209-06-0184 AOARD from AFOSR/KIST joint research program.

6. References

1. S. H. Fan, P. R. Villeneuve, J. D. Joannopoulos, and E. F. Schubert, Phys. Rev. Lett. **78**, 3294 (1997)
2. I. Schnitzer, E. Yablonovitch, C. Caneau, and T. J. Gmitter, Appl. Phys. Lett. **62**, 131 (1993)
3. S. Moeller, S. R. Forrest, J. Appl. Phys. **91**, 3324 (2002)
4. S. K. So, W. K. Choi, L. M. Leung, and K. Neyts, Appl. Phys. Lett. **74**, 1939 (1999)
5. A. dodabalapur, L. J. Rothberg, and T. M. Miller, Appl. Phys. Lett. **65**, 2308 (1994)
6. S. Tokito, T. Tsutsui, Y. Taga, J. Appl. Phys **86**, 2407 (1999)
7. T. Shiga, H. Fujikawa, and Y. Taga J. Appl. Phys **93**, 19 (2003)
8. A. Dodablapur, L. J. Rothberg, R. H, Jordan, T, M, Miller, R. E. Slusher, and J. M. Philips, J Appl. Phys **80**, 6954 (1996)
9. T. Fukuda, B. Wei, M. Ohashi, M. Ichikawa, and Y. Taniguchi, Jpn. J. Appl. Phys **46**, 642 (2007)
10. A. Chin and T. Y Chang, J. Ligthwave. Technol. **9**, 321 (1991)