Tandem Blue Top Emission OLEDs with Purcell Factor Considered Optical Simulation

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Keywords: OLED, Top Emission, Tandem structure, Purcell effect

ABSTRACT

In this paper, we report highly efficient tandem blue top emission OLEDs with our Purcell effect considered optical simulation method. Our fabricated three stack tandem top emission OLED device shows 84.5cd/A current efficiency and 740 blue index efficiency with reasonably good correlated optical simulation results.

1 Introduction

To date, top emission organic light-emitting diode (TEOLED), which emits light upward, is being actively studied as it is suitable for active-matrix OLED display due to higher efficiency in normal direction and better color purity. In addition, recently tandem blue TEOLED structure is actively studied for TV application. General structure of TEOLEDs is composed of a highly reflective anode and a semi-transparent cathode and they induce a strong micro-cavity effect [1]. In this structure, some of the light generated by the emitting layer (EML) escapes toward to the semi-transparent cathode, and the remaining light is reflected by reflective anode. Both reflective electrodes make internal constructive interference in the cavity structure, which is called micro-cavity effect. Due to such micro-cavity effect, optical simulation of TEOLED device is highly desired before making devices because the total thickness of organic layer is important. In case of tandem blue TEOLED, this optical simulation is more important because two or three electro-luminescence (EL) units are connected in the same cavity structure [2]. Each EL unit is connected using charge generation layer (CGL). To calculate optically this complex device condition, transfer matrix method with Fresnel equation is commonly used. However, there was almost no consideration about influence of emitter dipole in aspect of quantum-electrodynamic optics. When the emitter dipole is spontaneous emission state near electric field, its radiative decay rate is affected by Fermi's golden rule, so called Purcell effect. As the consideration of this Purcell effect, more accurate optical calculation is possible. Hence, we firstly reported the Purcell factor (PF) considered optical simulation method [3].

In this paper, we report highly efficient tandem blue TEOLEDs with comparison of optical simulation methods. We did optical simulation with and without PF consideration for tandem TEOLEDs. Based on these calculation, we fabricated second order single, second order 2-stack, and third order 3-stack TEOLEDs and we compared with optical calculated values as the number of EL units.

2 Experiment

The current density versus voltage-luminance (J-V-L) characteristics of fabricated TEOLED devices were measured by using Keithley SMU 2635A and Minolta CS-100A. Electroluminescence (EL) spectra and commission international de l'Eclairage (CIE) coordinates were obtained by using a Minolta CS-2000A.

The optical simulations of TEOLED devices were performed by using a commercially available SETFOS (Fluxim) program. The refractive index, extinction coefficient (k), photoluminescence (PL) spectrum of emissive layers and thickness of each layer were used as input parameters. The calculated values were noted based on the peak wavelength in green dopant, 475 nm. We calculated the current efficiency of device by using normal method and optically simulated electroluminescence spectrum in normal direction. In order to consider Purcell effect in our calculation, we calculated total power dissipation, which is proportional to the PF. Combining the calculated common spectrum and their total power dissipation in visible wavelength region, we derived new spectrum which is affected by power dissipation (Purcell method). We calculated efficiency of Purcell method by using newly derived spectrum.

3 Results

The simple optical calculation process for applying the PF is shown in the following equation [3].

$$\mathrm{EQE} = \frac{\Gamma_r}{\Gamma_r + \Gamma_{nr}} \times I_{OC}(\lambda) \quad (1)$$

In this equation, Γ_r, Γ_{nr} and $I_{OC}(\lambda)$ are mean the radiative decay rate in the cavity, nonradiative decay rate and outcoupling efficiency, respectively. applying the PF in equation 1 is equivalent to the following equation.

$$\mathrm{EQE}^* = \frac{F(\lambda)\Gamma_r}{F(\lambda)\Gamma_r + \Gamma_{nr}} \times \frac{I_{OC}(\lambda)}{F(\lambda)} \quad (2)$$

In equation 2, Since the PF is the total power emitted in the cavity, Γ_{nr} cannot be multiplied by the PF because it is not related to the nonradiative decay rate. In case of $I_{OC}(\lambda)$ factor, it is an expression that includes outcoupled power. Since the PF is proportional to the power dissipation, the $I_{OC}(\lambda)$ factor must be divided by the PF.

$$\mathrm{EQE}^* \propto \frac{I_{OC}(\lambda)}{F(\lambda)} \quad (3)$$

Finally, EQE considering PF is as shown in Equation (3). In summary, if the EQE value obtained through the normal method is divided by the decay rate, which is PF, the efficiency considering PF can be calculated.

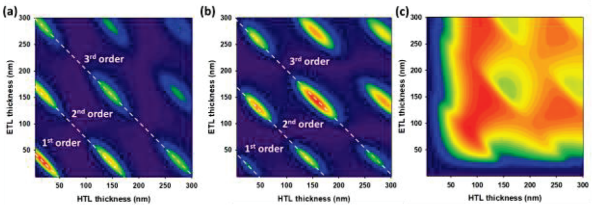


Figure. 1 Radiance distribution of blue emitter depending on HTL and ETL thickness that calculated by **(a)** normal method, **(b)** Purcell method and **(c)** dipole decay lifetime.

As shown in Fig.1, we calculated radiance distribution of the cavity condition according to HTL and ETL variation in blue EML. Fig. 1 (a) and (b) are radiance values calculated using the normal method and the purcell method, respectively. Fig. 1 (c) shows the lifetime of dipole according to HTL and ETL thickness variation. Since the lifetime of dipole is inversely proportional to the decay rate, the calculated value of Fig. 1 (b) can be obtained using the PF. Fig. 1 (a) shows the highest radiance in the first order condition, but it can be seen that the radiance decreases in the higher order. On the contrary, in the case of Fig. 1 (b), the lowest radiance value is shown in the first order condition, and the radiance value increases in the high order condition. Through the cavity condition obtained in Fig. 1 (b), we fabricated the device as follows.

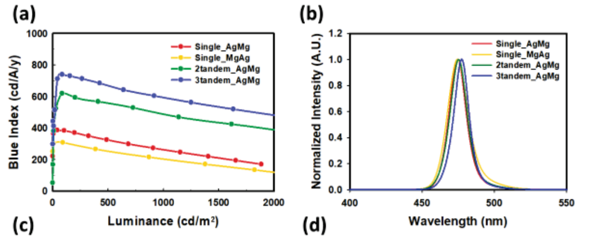
Single_MgAg (SM): Ag (150nm)/ITO (10nm)/HIL1 (75nm) /HIL2 (7nm)/HTL (78nm)/Blue_EML (25nm)/ETL (30nm)/LiF 1.5nm)/Mg:Ag(10:1) (20nm)/CPL (60nm)

Single_AgMg (SA): Ag (150nm)/ITO (10nm)/HIL1 (75nm) /HIL2 (7nm)/HTL (73nm)/Blue_EML (25nm)/ETL (30nm)/LiF 1.5nm)/Ag:Mg(10:1) (24nm)/CPL (60nm)

2stack_AgMg (2A): Ag (150nm)/ITO (10nm)/HIL (7nm) /HTL (22nm)/Blue_EML1 (25nm)/CGL (87nm) /Blue_EML2 (25nm) /ETL (30nm)/LiF (1.5nm) /Ag:Mg(10:1) (24nm)/CPL (60nm)

3stack_AgMg (3A): Ag (150nm)/ITO (10nm)/HIL (7nm) /HTL (22nm)/Blue_EML1 (25nm)/CGL1 (91nm) /Blue_EML2 (25nm) /CGL2 (97nm)/Blue_EML3 (25nm)/ETL (30nm)/LiF (1.5nm) /Ag:Mg(10:1) (24nm)/CPL (60nm)

Fig. 2 (a) and (b) show the efficiency and EL spectrum of the fabricated devices, and Fig. 2 (c) shows the performances of the fabricated devices and the calculated efficiency ratio using the normal method and the purcell method. We set SA device as a reference (1.00) to compare the efficiency of the calculated values in each device. The SM device showed 0.79 lower experimental values than the SA device, and the calculated values of the normal method and the purcell method were 0.66 and 0.74. The 2A and 3A devices showed experimental values of 1.61 and 1.91, respectively, and calculated values of 1.91, 1.80 (2A) / 2.13 and 2.39 (3A) were obtained for the normal method and the purcell method. These results show that the Purcell method is more accurate for single and 2stack tandem TEOLED devices. However, there is a slightly difference between the calculated value of the purcell method and the experimental value in the 3stack device, because the peak of the 3stack device is not optimized. For accurate comparison, analysis should be performed after peak optimization through precise cavity condition control. More detailed of cathode unit property and device performances will be present at the conference.



(c)

Device	Single AgMg	Single MgAg	2stack AgMg	3stack AgMg
C.E. (max)	37.1 cd/A	32.5 cd/A	62.5 cd/A	84.5 cd/A
Spectral peak	475 nm	475 nm	475.5 nm	477.5 nm
FWHM	14 nm	18 nm	14 nm	13nm
CIE coordinates (max)	(0.111, 0.095)	(0.110, 0.107)	(0.110, 0.100)	(0.103, 0.115)
Blue index (max)	386 (1.00) cd/A/y	307 (0.79) cd/A/y	619 (1.61) cd/A/y	740 (1.91) cd/A/y
Normal method	1.00	0.66	1.91	2.13
Purcell method	1.00	0.74	1.80	2.39

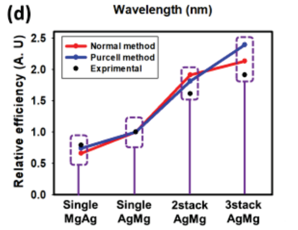


Figure. 2 (a) the luminance-blue index efficiency characteristics, **(b)** electroluminescence (EL) spectra, **(c)** fabricated device performances and optically calculated device performances. **(d)** comparison of experimental values with normal method and Purcell method.

4 Conclusions

We fabricated highly efficient various tandem blue TEOLEDs with our Purcell effect considered optical simulation method. Our fabricated 3-stack tandem device shows 84.5cd/A current efficiency and 740 blue index efficiency. We also compared with optical simulation results with the normal and PF methods. The optical simulation method with consideration of Purcell effect was more accurate to predict the performances of various tandem TEOLEDs

Acknowledgement

This work was supported by the Technology Innovation (20014668, Development of flexible nano light-emitting device with more than 100% color space of BT. 2020) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea)

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