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Characteristics of blue organic light emitting diodes with different thick emitting layers

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ABSTRACT

We fabricated blue organic light emitting diodes (called blue OLEDs) with emitting layer (EML) of diphenylanthracene derivative 9,10-di(2-naphthyl)anthracene (ADN) doped with blue-emitting DSA-ph (1-4-di-[4-(N,N-di-phenyl)amino]styryl-benzene) to investigate how the thickness of EML and hole injection layer (HIL) influences the electroluminescence characteristics. The driving voltage was observed to increase with increasing EML thickness from 15 nm to 70 nm. The maximum external quantum efficiency of 6.2% and the maximum current efficiency of 14 cd/A were obtained from the OLED with 35 nm thick EML and 75 nm thick HIL. High luminance of 120,000 cd/m^2 was obtained at 7.5 V from OLED with 15 nm thick EML.

1. Introduction

Blue organic light emitting diodes (blue OLEDs) have been interested because of applications to full-color flat-panel display and lighting. Blue emitter is used as one of the three primary color sources or as the color converter light source to obtain green and red emissions from the fluorescent materials. Compared with the green and red OLEDs, the conventional blue OLEDs have lower efficiency and shorter operational lifetime [1].

Continual efforts have been made towards exploring blue-emitting materials and device structures to improve the OLED performance. In the present paper we study the device structure (especially layer thickness) to achieve a high performance of blue OLED. Here we use DSA-ph (1-4-di-[4-(N,N-di-phenyl)amino]styryl-benzene) as a blue emitting material because of high efficiency and stability [2].

OLEDs consist of various thin layers such as hole injection layer (HIL), hole transport layer (HTL), emitting layer (EML), electron transport layer (ETL), and electron injection layer (EIL). Variation of the thickness of organic layers affects not only the electrical and optical properties of the devices but also the efficiency. We fabricate the blue DSA-ph OLEDs with a different HIL thickness d_{HIL} and a different EML thickness d_{EML}.

We report the change in the EL color, current efficiency, power efficiency, and external quantum efficiency of the multi-layer OLED devices by the variation of relative thicknesses of HIL and EML under a fixed $d_{HIL} + d_{EML}$ of 110 nm. We show the optimal thickness to obtain high OLED performance.

2. Experimental procedure

We fabricated PSA-ph OLED with the following layer structure: IZO/2-TNATA:2%F4-TCNQ(d_{HIL})/α-NPD(10 nm)/β-ADN:5%DSA-ph(d_{EML})/Alq_3(20 nm)/LiF(0.9 nm)/Al(100 nm).

The layer thickness of each layer is indicated. DSA-ph was used as the blue dopant in EML, and β-ADN (9,10-di(2-naphthyl)anthracene) was used as the host. The IZO (indium zinc oxide), 2-TNATA (4,4′,4″-tris(2-raphpthylphenylamino)triphenylamine) with 2% F4-TCNQ (tetrafluoro-tetracyanoquinodimethane), α-NPD (N,N′-di(1-naphthyl)-N,N′-diphenylbenzidine), and Alq_3 (tris(8-quinolinolato) aluminum) were selected as materials for transparent anode, HIL, HTL, and ETL, respectively. We used IZO on behalf of conventional ITO (indium tin oxide) because the work function (5.1 eV) is higher than that of ITO [3]. Alq_3 was selected since it is known as a good electron transportation material [4].

The HIL thickness d_{HIL} and EML thickness d_{EML} were changed variously in keeping the sum of $d_{HIL} + d_{EML}$ constant (110 nm), i.e., d_{EML} was selected as 15, 25, 35, 50, and 70 nm, and correspondingly d_{HIL} was selected as 95, 85, 75, 60, and 40 nm, respectively, The layer structure of the device with d_{EML} = 35 nm

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and d_{HIL} = 75 nm is shown in Fig. 1, together with the HOMO and LUMO energy levels of each layer.

The OLED device was fabricated by thermal evaporation method. The pressure was lower than 7×10^{-4} Pa during the evaporation of organic materials and Al cathode. The deposition rate was lower than 0.3 nm/s. All the device processes were performed without breaking the vacuum. The layer thickness was measured with a quartz crystal monitor.

3. Experimental results and discussion

Fig. 2 shows the EL spectra of the OLED devices with various EML thicknesses, which were obtained at about 100,000 cd/m^2. Vibronic structure with peaks at 471, 505, 544, and about 592 nm are observed, which are attributed to the 0–0, 0–1, 0–2, and 0–3 vibrational transitions in DSA-ph, respectively. The vibronic structure is found to change by change of the EML thickness. Usually the 0–0 component at 471 nm is much higher than the other vibrational components [5,6]. However, the intensity ratio of the 0–1 component at 505 nm to the 0–0 component at 471 nm decreases with increasing the EML thickness. The ratio is called Huang–Rhys parameter S [7,8]. The parameter S is 0.58, 0.64, 0.67, 0.73, and 0.96 for devices with d_{EML} = 15, 25, 35, 50, and 70 nm, respectively. It is suggested that such a change of the EL spectra is due to the microcavity effect, because it gives rise to a change in the spectral line shape by the light reflection and interference depending on the layer thickness in the multi-layer structure [9–11].

Spectral change means color change of emission from OLED. In fact the color of the emission from OLED device changes from blue to blue-green with increasing the EML thickness from 15 nm to 70 nm as seen in Fig. 4 where the Commission Internationale d'Eclairage (CIE) chromaticity coordinates are plotted for the five devices.

It is noted that the very weak emission is observed at about 422 nm (Fig. 2). The 422 nm emission enhances with decreasing the EML thickness as shown in Fig. 3 where the ratio of the 422 nm EL intensity to the 471 nm DSA-Ph EL intensity are plotted against EML thickness. It might be conceivable to attribute the 422 nm emission to ADN host because it has an EL band at 430–435 nm [12,13]. It, however, is difficult to understand that its appearance depends on the EML thickness. Therefore it is more reasonable that the 422 nm emission is attributed to molecule α-NPD which is used as HTL. This indicates that a leakage of electrons from EML towards HTL enhances with decreasing the EML thickness. This is caused by the increase of electric field in the EML with decreasing the EML thickness, resulting in increase of number of electrons which penetrate the interface of HTL/EML and reach the HTL.

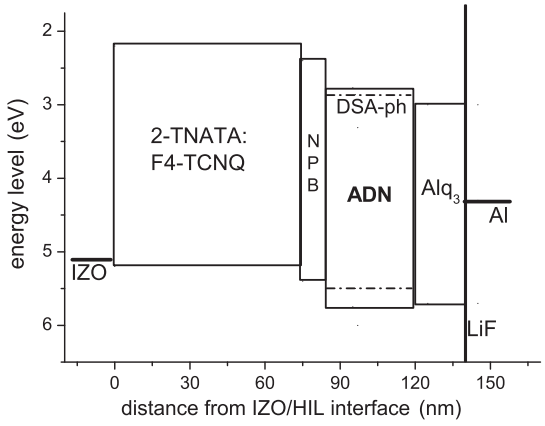

Fig. 1. Layer configuration and energy level diagram of the OLED device with d_{EML} = 35 nm and d_{HIL} = 75 nm.

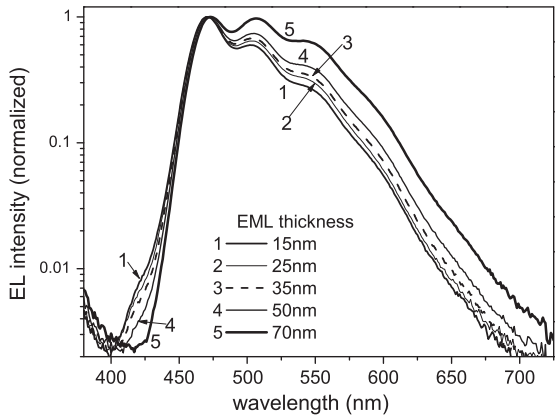

Fig. 2. EL spectra of the OLED devices with various EML thicknesses, which were obtained at about 100,000 cd/m^2.

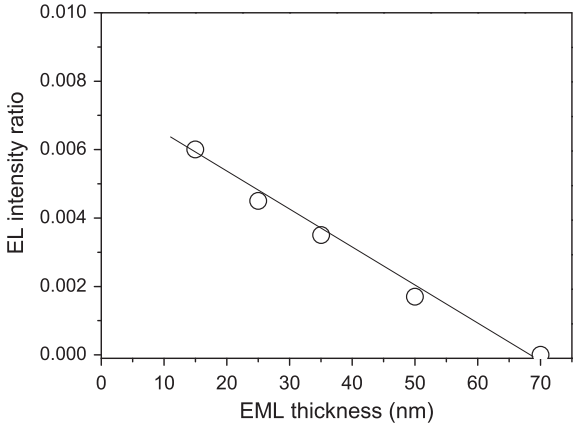

Fig. 3. Ratio of the 422 nm a-NPD EL intensity to the 471 nm DSA-Ph EL intensity plotted against EML thickness.

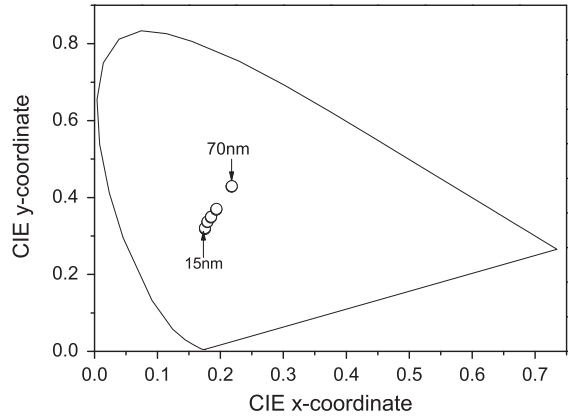

Fig. 4. The CIE chromaticity coordinates of the devices with d_{EML} = 15, 25, 35, 50, and 70 nm.

Fig. 5 plots the luminance against the applied voltage for the five OLED devices with different EML and HIL thicknesses. The turn-on voltage becomes higher with increasing the EML thickness. Luminance of 10,000 cd/m^2 is obtained at low voltage of about 5.0 V from OLED with EML thickness of 15 nm. When the driving