Enhancement mechanisms of luminance efficiency in red organic light-emitting devices fabricated utilizing a double electron transport layer consisting of an Al-doped layer and an undoped layer

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Keywords: double electron transport layer, red OLEDs, Al-doped layer, and luminance efficiency

Abstract

The luminance efficiency of the red organic light-emitting devices fabricated utilizing a double electron transport layer (ETL) consisting of an Al-doped and an undoped layer was investigated. The Al atoms existing in the ETL acted as hole blocking sites, resulting in an increase in the luminance efficiency.

1. Introduction

Organic light-emitting devices (OLEDs), which offer many advantages of low cost, fast response, and low power consumption, have been emerged as excellent candidates for the next generation flat panel display [1-5]. Many studies on efficiency improvement of OLEDs have been performed by enhancing the recombination probability and the balance of carriers in emitting layer (EML) of OLEDs [6-8]. OLEDs with a lithium (Li)-doped tris(8-hydroxyquinoline)aluminum (Alq_3) electron transport layer (ETL) or a hole-blocking layer of an Al-doped organic layer have been particularly attractive because of interest in fabricating OLEDs with a high efficiency [9-13]. Even though many investigations concerning the efficiency enhancement of OLEDs utilizing a single ETL have been reported, very few studies on highly efficient OLEDs with a double ETL consisting of an Al-doped layer and an undoped layer have been performed. This paper reports data for enhancement mechanisms of luminance efficiency in red OLEDs fabricated utilizing a double ETL consisting of an Al-doped layer and an undoped layer. The electrical and optical properties of the red OLEDs fabricated utilizing a double ETL consisting of an Al-doped layer and an undoped layer formed by using organic molecular beam deposition were investigated. Current density-voltage, efficiency-current density, electroluminescence (EL) measurements were carried out to investigate the electrical properties, the movement of emission zone, and the efficiency improvement of the red OLEDs.

2. Experimental

The sheet resistivity of the indium-tin-oxide (ITO) thin films coated on glass substrates used in this study was 15 Ω/□. The ITO substrates were cleaned using acetone and methanol at 60°C for 5 min, and then rinsed in de-ionized water thoroughly. After the chemically cleaned ITO substrates had been dried by using N_2 gas with a purity of 99.9999%, the substrates were treated with an oxygen plasma for 10 min. The red OLEDs with a single or a double ETL were fabricated on ITO-coated glass substrates and consisted of the following structure from the bottom: ITO as an anode electrode, *N*,*N*-bis-(1-naphthyl)-*N*,*N*-diphenyl-1,1-biphenyl-4,4-diamine (NPB) (50 nm) as a hole transport layer (HTL)/1.0% DCM1-doped Alq_3 (40 nm) as an EML/an undoped Alq_3 (30 nm) single ETL or a double ETL consisting of an Al-doped Alq_3 (15 nm) layer and an undoped Alq_3 layer (15 nm)/Al (100 nm) as a cathode electrode. The red OLEDs with a single ETL and a double ETL are denoted as devices I and II, respectively. The schematic diagrams of the OLED structures used in this study are shown in Fig. 1. The organic layers were deposited at a substrate temperature of 27°C and a system pressure of 5×10^{-8} Torr. The deposition rates of the organic layers and the metal layers were approximately 0.1 and 0.5 Å/s, respectively. The deposition rates were controlled by using a quartz crystal monitor. The size of the emitting region in the pixel was 3×3 mm². The current density-voltage and the luminance efficiency-current density characteristics of the red OLEDs were measured on a programmable electrometer with built-in current and voltage measurement units (Keithley 236). The EL spectra were measured by using a spectrometer (Perkin-Elmer LS20B).

3. Results and discussion

Figure 2 shows the current density-voltage, the luminance-voltage, and the luminance efficiency-current density characteristics for devices I and II. The current density of device II with a double ETL decreased in comparison with that of device I because the Al atoms in the double ETL acted as electron trap

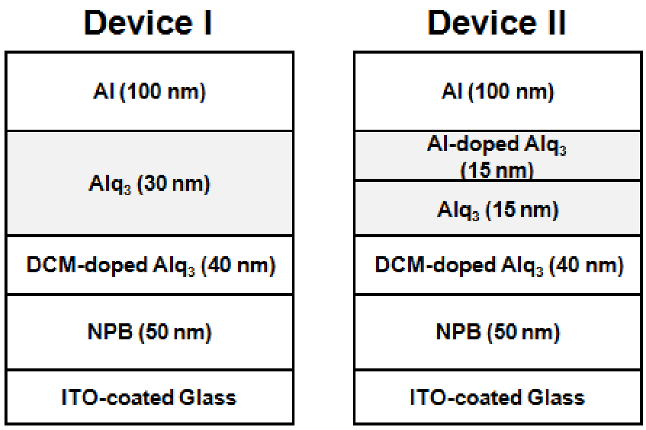

Fig. 1. Schematic diagrams for OLEDs of devices I and II.

sites. The difference of the current densities between devices I and II decreased with increasing applied voltage because the more electron trapping sites were occupied by the electrons injected from the cathode. Because the conductivity of the Al-doped ETL was lower than that of the HTL, the voltage across the ETL at high voltages was larger than that across the HTL, resulting in an increase in the number of electrons injected from the cathode to the EML. While the luminance of device I at low voltages was larger than that of device II, that of device II at high voltages exceeded the luminance of device I because the electron injection in device II at high voltages increased. The luminance efficiency of device II was significantly enhanced in comparison with that of device I. The double ETL consisting of the Al-doped Alq_3 layer and the undoped Alq_3 layer at high voltages decreased the holes injected from the anode to the EML, resulting in an increase in the luminance efficiency of device II with a double ETL.

The movement of the recombination zone due to the insertion of the Al-doped layer was clarified by using the EL spectra shown in Fig. 3. The dominant peaks at 2.45 and 2.1 eV corresponded to the Alq_3 and DCM1 layers, respectively. While the EL spectrum of device I contained the emission peaks related to the Alq_3 and DCM1 layers, that of device II showed only the DCM1 peak. Even though the recombination region of device I extended over the DCM1-doped Alq_3 EML

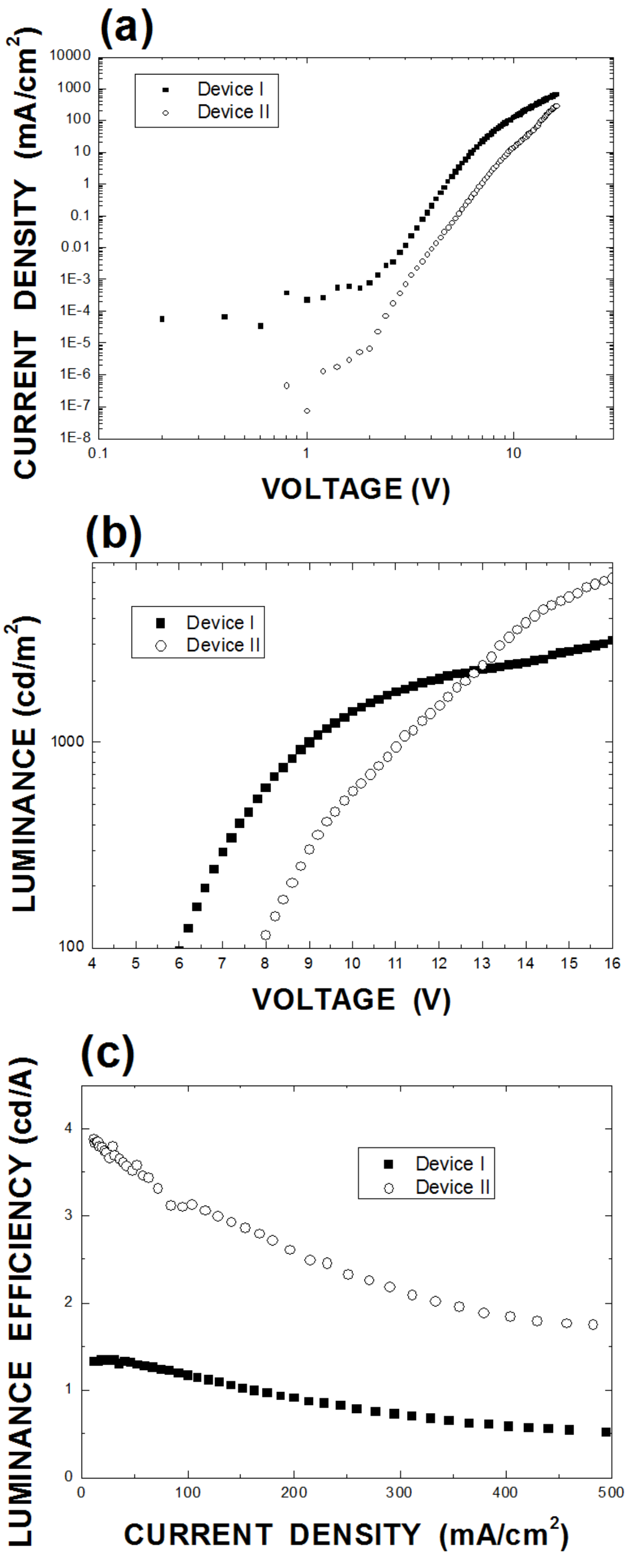

Fig. 2. (a) Current densities as functions of the applied voltage, (b) luminances as functions of the applied voltage, and (c) luminance efficiencies as functions of the current densities for OLEDs of devices I and II.

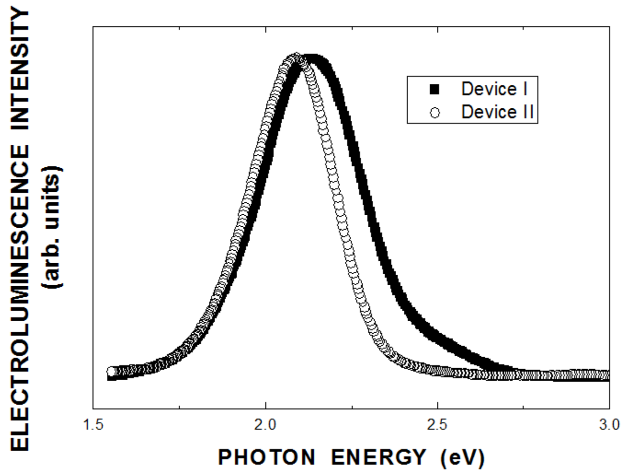

Fig. 3. Electroluminescence spectra at 14 V of devices I and II.

and the undoped Alq_3 ETL, that of device II existed only in the EML. The Al atoms in the ETL trapped the electrons which were injected from the cathode into the EML, and they decreased the conductivity of the Al-doped ETL, resulting in a decrease in the applied voltage to the HTL. Therefore, the magnitude of the holes which were transferring from the HTL to the EML decreased, and the recombination zone of device II with a double ETL was shifted to the EML region, resulting in an increase in the luminance efficiency of the red OLEDs.

4. Summary

The electrical and optical properties of the red OLEDs with a double ETL consisting of the Al-doped Alq_3 layer and the undoped Alq_3 layer were investigated. While the current density of device II with a double ETL was smaller than that of device I with a single ETL, the luminance efficiency of device II was larger than that of device I. The improvement of the luminance efficiency in the red OLEDs with a double ETL originated from the shift of the recombination zone to the EML due to a decrease in the conductivity of the Al-doped Alq_3 layer. These results indicate that highly efficient OLEDs can be fabricated using a double ETL consisting of an Al-doped Alq_3 and an undoped Alq_3 layers.

5. Acknowledgements

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. R0A-2007-000-20044-0).

6. References

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