Low voltage organic light-emitting devices with new electron transport layer

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Abstract

We have developed low voltage operating OLEDs with new electron transport layer. The device having a structure of ITO/2TNATA/HTL:Rubrene(1%)/HTL /new ETL/LiF/Al have been used. The voltage for achieving 1,000 cd/m^2 was 4.1 V, whereas the turn on voltage for the brightness of 1 cd/m^2 was 2.8 V. This high luminance at low operating voltage is caused by the high current density, resulting from high electron conduction property of the new electron transport layer.

1. Introduction

Organic light-emitting diodes(OLEDs) have been intensively investigated as alternative to liquid crystal for realizing flat-panel display(FPD) since the first efficient device was demonstrated, because they can be color tuned from blue to red applications. This kind of device exhibits high efficiency, fast response, wide viewing angle, and full-color capability [1]. Recently, OLEDs successfully entered into the display market as a sub-window and main- window display of a cellular phone and display for MP3. Hence, OLEDs demanded long life time , and low power consumption display. Low voltage operation of organic light-emitting devices (OLEDs) is one of the critical issues on realizing low power consumption displays. To lower the power consumption and the driving voltage, enhancing the carrier injection from the electrode to the transport layer and increasing the transport conductivity are two approaches. Also, increasing the electron conduction in the electron transport layer(ETL) seems a more promising approach to achieve a charge balance compared to reducing the amount of holes by doping the hole transport layer(HTL), since the ETL usually exhibit poor electron conductivity, limited the power efficiency. The approaches for low voltage devices have been focused on the doping of several dopants such as Li, Cs_2CO_3, WO_3, F_4TCNQ into the organic hole and/or electron transport and/or injection layers [2]. However, the doping of these materials could induce reliability issues by the diffusion of these dopants inside the organic layers [3]. We have developed the new electron transport layer for the low voltage operation of OLEDs. The operating voltage of the device with new layer is substantially reduced without any impurity doping into the transport layer [4~6].

2. Experimental

ITO coated glasses having sheet resistance of 10Ω/□ were used as the substrates for the device fabrication. ITO anodes were patterned by photolithography process and wet etching. The patterned substrates were cleaned with methanol and deionized water followed by exposure by exposure to oxygen : argon plasma. All organic and metal layer were deposited by using vacuum thermal evaporation technique in a base pressure of about 2×10^{-6} torr. A 15nm thick 4,4',4''-tris[N-(2-naphthyl)-N-phnyl-amimo]triphenylamine(2-TNATA) was used as a hole injection layer and a 40nm thick 4,4',-bis[N-(1-naphthyl)-N-phenyl-amino] biphenyl (α-NPD) layer was used as hole transport and emission layer. A 60nm thick new ETL was used as an electron transport layer. All organic layers were deposited with an evaporation rate of 0.1nm/sec. Thereafter, the electron injection layer and cathode, LiF/Al were deposited. All the completed devices were encapsulated in a nitrogen atmosphere glove box without exposing to air. A conventional OLED having the configurations of ITO/2-TNATA(15nm) / α-NPD (40nm) / Alq_3(60nm) / LiF(0.5nm) / Al(100nm) was also fabricated for comparison. The structure of the OLEDs s shown in Fig. 1 The current density-voltage (J-V) and luminance-voltage (L-V) characteristics of these devices were measured simultaneously with Keithley 2400 Source Meter and Minolta CS100 Luminance Meter. The electroluminescence (EL) spectra were measured with Minolta CS1000 spectrometer.

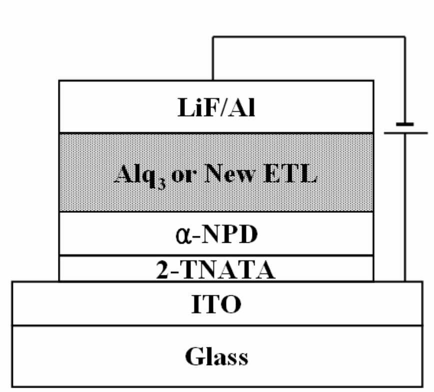

Fig. 1.The structure of OLEDs with new ETL

3. Results and discussion

We have fabricated organic light emitting devices with new electron transport layer. Fig. 2 shows the current-voltage characteristic of the OLEDs with structures of (a) ITO/2TNATA(15 nm)/α-NPD(40 nm)/Alq_3(60 nm)/LiF/Al and (b) ITO/2TNATA(15 nm)/α-NPD(40 nm)/new ETL (60 nm)/LiF/Al. The current-voltage curves were significantly modified by simple replacement of Alq_3 with a new ETL layer. The voltages for obtaining current density of 100 mA/cm^2 were 4.9 and 11.8 V for the new ETL and Alq_3 ETL devices, respectively, indicating substantial shift (~ 6 V) of current-voltage curve toward the lower voltage side.

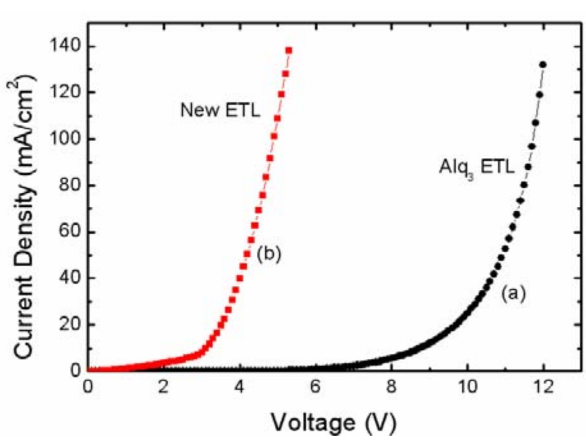

Fig. 2. Current density vs. voltage curves of (a) Alq_3 ETL and (b) new ETL OLEDs.

Fig. 3 shows the luminance-voltage characteristics of the devices with Alq_3 ETL and new ETL layers. The voltages for obtaining brightness of 100cd/m^2 were 7.3V and 3.7V for the Alq_3 ETL and new ETL layer, respectively. The turn on voltage which is defined to voltage for achieving 1 cd/m^2 were 2.8 V and 4.0V for the Alq_3 ETL and new ETL layer, respectively. The new ETL layer has good electron conduction characteristics.

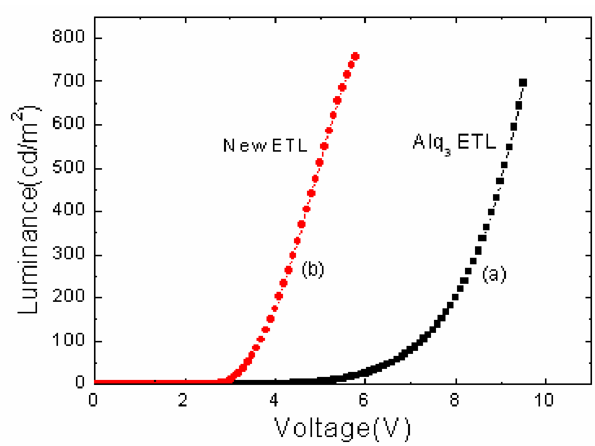

Fig. 3. Luminance vs. voltage curves (a) Alq_3 ETL and (b) new ETL OLEDs.

Fig. 4 shows the electroluminescence spectra for the device with a new ETL. The devices structure were (a) ITO/2-TNATA (15nm)/α-NPD : rubrene(1%) (40nm)/new ETL(60nm)/LiF/Al, (b) ITO/2-TNATA(15nm)/α-NPD (30nm)/α-NPD : rubrene(1%) (10nm) /new ETL (60nm)/LiF/Al and (c) ITO / 2-TNATA(15nm)/α-NPD : rubrene(1%) (10nm) /α-NPD (30nm) / new ETL (60nm)/LiF/Al. The EL spectra of the devices show strong peak at 556nm, 466nm, and 555nm for the device (a), (b), and (c), respectively. Hence, the device (a) and (c) results in yellow emission from rubrene molecules and device (b) emit blue light from α-NPD molecules. The blue emission in device (b) means that most of recombination takes place in undoped α-NPD layer. Similarly, the yellow emission in device (c) means that most of recombination takes place in the rubrene doped α-NPD layer adjacent to the 2-TNATA layer. This result demonstrates that the hole – electron recombination zone for the device with a new ETL is located at 2-TNATA/rubrene doped α-NPD interface.

Fig. 5 shown the current density-voltage-luminance curve of ITO/2-TNATA/α-NPD doped with rubrene (1%)/α-NPD/new ETL/LiF/Al device. The voltage for obtaining current density of 100 mA/cm^2 was 5.3V for the new ETL device.

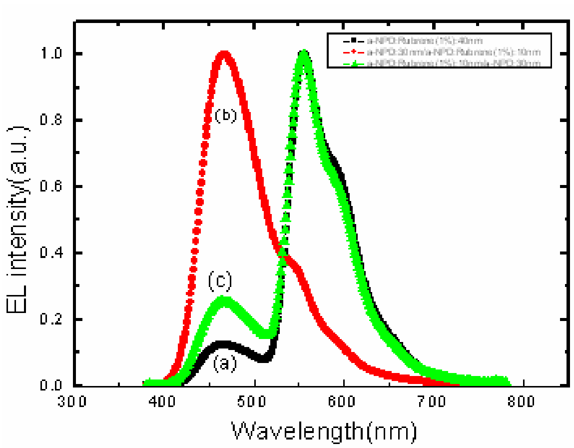

Fig. 4. EL spectra of rubrene doped devices with the organic layer structures of (a) α-NPD:rubrene (1%, 40 nm)/ETL, (b) α-NPD(30 nm)/α-NPD:rubrene(1%, 10 nm)/ETL and (c) α-NPD:rubrene(1%, 10 nm)/α-NPD (30 nm)/ETL

The turn on voltage which is defined to voltage for achieving 1 cd/m^2 was 2.8 V. The brightness rapidly increases to 1,016 cd/m^2 by increasing the voltage only 1.3 V above the turn on voltage. Also, the voltage for achieving 3,500 cd/m^2 was 5.0V. This rapid increase of brightness with the voltage is caused by the good electron conduction properties of new electron transport layer.

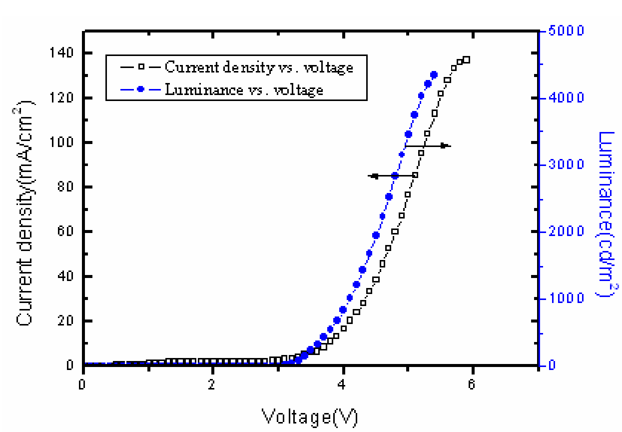

Fig. 5. Current density-voltage-luminance cureves for the devices with a new ETL.

Fig. 6 shown the current efficiency-current density curve of ITO/2-TNATA/α-NPD doped with rubrene (1%)/α-NPD/new ETL/LiF/Al device. The maximum current efficiency is 5.1cd/A at the current density of 28.3 mA/cm^2. The efficiency of the device with new ETL layer was about 5 cd/A which is slightly lower compared to the rubrene doped devices, but it can be further improved by optimization of the device. These results show the possibility of low voltage operating organic light emitting devices without any impurity doping into the organic layer or without pin structure.

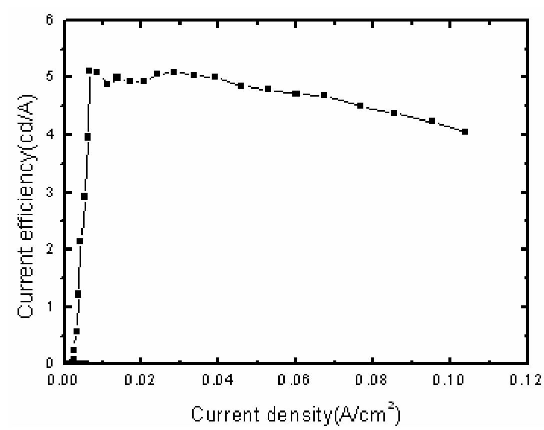

Fig. 6. Current efficiency vs. current density for the device with new ETL.

4. Summary

We have developed low voltage operating OLEDs with new electron transport layer. The brightness of 1,016 cd/m^2 can be obtained at 4.1 V by the new ETL layer with the device structure of ITO / 2TNATA / α-NPD doped with rubrene (1%) / α-NPD /new ETL / LiF/Al. The turn on voltage which is defined to voltage for achieving 1 cd/m^2 was 2.8 V. The driving voltage of OLEDs can be substantially lowered by the newly developed ETL layer which has good electron conduction properties.

5. References

1. C. W. Tang, S. A. VanSlyke, Appl. Phys. Lett, 51, 1987, 913-915
2. Q. Huang, K. Walzer, M. Pfeiffer, V. Lyssenko, G.

He, and K. Leo, Appl. Phys. Lett., 88, 2006, 113515
3. Yu-meng Shi, Zhen-bo Deng, Deng-hui Xu, JingXiao, Displays, 27(2006) 166.
4. H.H.Fong, K.C. Lun, S.K. So, Chem. Phys. Lett., 353(2002) 407.
5. W. Brutting, T. Dittrich, V. Petrova-Koch, S. Karg, W. Brutting, Appl. Phys. Lett., 71(1997) 2686.
6. R.G. Kepler, P.M. Beeson, S. J. Jacobs, R. A. Anderson, M. B. Sinclair, V. S. Valencia, P. A . Cahill, Appl. Phys. Lett. 66(1995) 3618.