Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp509-510

High Efficiency Electrophosphorescence Red OLEDs Using a Thin BPY-OXD Cleaving Layer in an Ir-complex Doped Emitter Layer

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1. Introduction

Recently, organic light-emitting devices (OLEDs) have received much attention due to their application to flat panel displays. OLEDs using phosphorescent dyes doped into charge-transporting hosts as emissive layer have also attracted intensive attention due to the highly efficient emission compared to conventional fluorescent OLEDs [1-2]. A maximum internal efficiency of near 100% of phosphorescence devices could be harvested by using iridium [$Ir(ppy)_3$] complexes as the red organic emitting dopants [3]. Charged carriers usually have extremely low mobilities in the organic materials used in OLEDs. The electron and hole mobilities in the electron transporting layer (ETL) and hole transporting layer (HTL) are as low as 10^{-5} and 10^{-3} cm^2/Vs, respectively [4]. It is generally recognized that balancing carrier injection in the emitting layer (EML) and increasing the utilization rate of the exciton are crucial to the high efficient OLEDs. In other words, it is important to balance the numbers of holes and electrons injected to the emitter layer to achieve high recombination efficiencies.

One can propose the new ETL organic material 1,3-Bis[2-(2,2'-bipyridin-6-yl)-1,3,4-oxadiazol-5-yl]benzene (Bpy-OXD) with high performance (high-speed transportation of electrons and good operational durability) [5]. Efficient Bpy-OXD ETL materials provide some advantages, such as lowering the operating voltage and power consumption. Moreover, the Bpy-OXD ETL materials have wide band transition energy, in other words, deeper highest occupied molecular orbitals (HOMO), and can also serve as hole blocking layer (HBL). The Other used method to achieve the high efficient OLEDs is to insert a cleaving layer into the EML which is divided into two sub-EMLs to design a high efficient Ir-complex based electrophosphorescence OLEDs. In this study, we report the fabrication and characterization of the OLEDs using a thin Bpy-OXD cleaving layer with various thicknesses in an Ir-complex doped emitter layer. It was found that the insertion of a thin Bpy-OXD cleaving layer in an Ir-complex doped emitter layer can balance the charge injection and transport, which is helpful in enhancing the performance of OLEDs. Current-voltage (I-V), electroluminescence (EL), and luminance characteristics of the fabricated OLEDs using a thin Bpy-OXD cleaving layer with various thicknesses in an Ir-complex doped emitter layer will also be reported.

2. Experimental and Result Discussions

We first cleaned the ITO glass substrates, with a sheet resistivity of 7Ω/sqr, by acetone, isopropyl alcohol, and de-ionized water. The chemically cleaned ITO glass substrates were subsequently pre-cleaned with O_2 plasma treatment at 10 Pa for 25min. To fabricated the devices, we thermally evaporated the organic layers and metal layers at 1~2Å/sec onto the substrates at base pressure of 1×10^{-5} Torr. OLED devices were then fabricated with a 25nm-thick m-MTDATA as the hole injection layer and a 45nm-thick NPB as the HTL. A 25nm-thick Bpy-OXD and a 0.3nm-thick LiF were as the ETL and electron buffer layer, respectively. The [$CBP:Ir(piq)_2(acac)$] was served as the EML which the total thickness was fixed at 30nm. In this structure, we insert a cleaving layer Bpy-OXD into the EML which is divided into two sub-EMLs with the same thickness of 15nm. Three devices with different thickness of Bpy-OXD cleaving layer were fabricated. The thicknesses of Bpy-OXD cleaving layer were 5, 10, and 15nm for devices B, C, and D, respectively. Samples without the Bpy-OXD cleaving layer were also prepared for comparison (i.e. sample A). ITO and Al were used as transparent anode electrode and reflective cathode, respectively. The active area of devices is $4\times4mm^2$. All devices were encapsulated in glove box. Fig.1 shows the device structure and the proposed energy level diagram, where the lowest unoccupied molecular orbital (LUMO) and the HOMO levels were respectively cited from the literature [6].

Figure 2 shows J-V characteristics of the four fabricated devices. The operating voltage was defined as the voltage with a current density of 100 mA/cm^2. It was found that when we insert a 5 nm-thick Bpy-OXD cleaving layer into EML, the operating voltage was decreased from 10.4 to 9.0V. The decrease of operating voltage attributes to two impactful exciton formation zones and better balance of the carrier injection in the two sub-EMLs, where the recombination rate of holes and electrons can be easily enhanced such that the operating voltage can also effectively reduced. It can be found that the operating voltage increases with the increasing thickness of Bpy-OXD cleaving layer from 5 to 15 nm. It indicates that when the proper thickness of Bpy-OXD is found, an optimal hole and electron ratios present in the two sub-EML regions.

Figure 3 shows measured J-L characteristics for these four OLEDs. It can be seen that output intensity of the four devices increases with the injection current initially and subsequently starts to saturate for all these four devices. It was also found that the luminance of device A without the Bpy-OXD cleaving layer was the lowest among the four OLEDs. The maximum brightness observed from device B could reach 9830 cd/m^2. In contrast, the maximum brightness of device C and device D were 6420 and 4640 cd/m^2, respectively. These values indicate that we could achieve the device with the best luminance performance from the OLED with this Bpy-OXD cleaving layer into the EML. Fig.4 shows the L-I characteristics of the four devices. It was found that current efficiency (cd/A) of device B was the highest among the four OLEDs. It was also found that the maximum current efficiency observed from device B could reach 4.36 cd/A. In contrast, the maximum current efficiency of device A, C and D were 2.66, 2.84, and 2.71 cd/A, respectively. These values indicate that the insertion of a thin Bpy-OXD cleaving layer in an Ir-complex doped emitter layer can effectively balance the charge injection and transport, which is helpful in enhancing the performance of OLEDs.

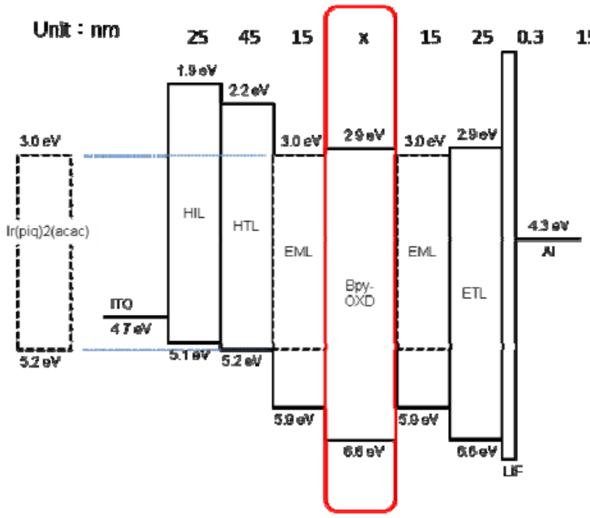

Fig. 1 The device structure of ITO/m-MTDATA (25nm)/NPB (45nm)/[CBP:Ir(piq)$_2$(acac)]$_A$ (15nm)/BPY-OXD cleaving layer/ [CBP:Ir(piq)$_2$(acac)]$_B$ (15nm)/ BPY-OXD (25nm)/LiF (0.3nm)/Al (150nm) and the proposed energy level diagram.

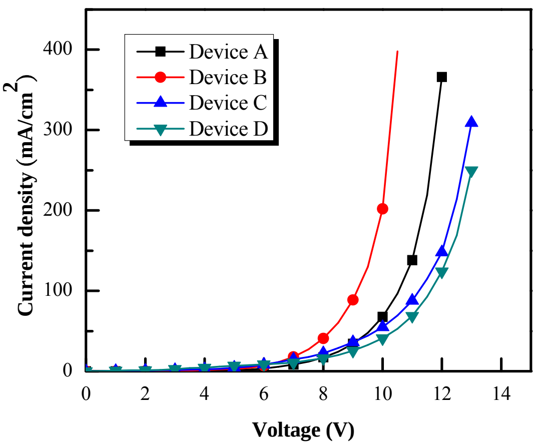

Fig. 2 The current density-voltage (I-V) characteristics of the four red OLEDs.

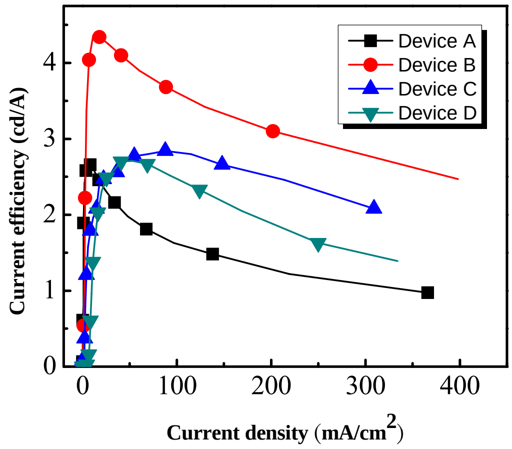

Fig. 3 The luminance-current density (L-I) characteristics of the four red OLEDs.

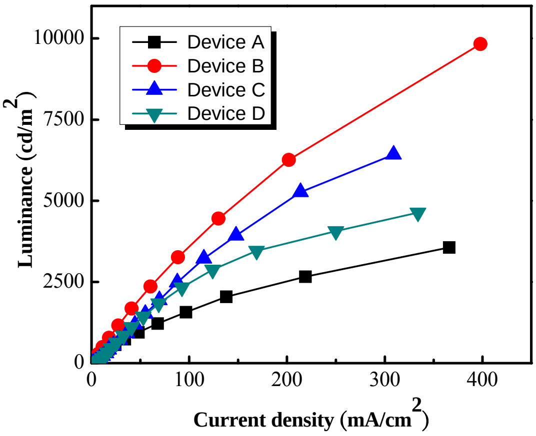

Fig. 4 The current efficiency-current density (L-I) characteristics of the four red OLEDs.

3. Conclusions

In summary, the high efficiency electrophosphorescent red organic light-emitting devices with the insertion of a thin Bpy-OXD cleaving layer in emitter layer have been fabricated. The maximum luminance and current efficiency of device B were 9830 cd/m^2 and 4.36 cd/A, respectively. These values prove clearly that we could achieve the device with the best luminance performance from the OLED with this Bpy-OXD cleaving layer into the EML.

Acknowledgements

This work was financially supported by National Science Council under contract NSC 98-2221-E-230-001.

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