Effect of the thickness of an emitting zone by the thin alkali compound films for highly efficient Alq_3-based OLEDs

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Abstract

Highly efficient and bright organic light-emitting diodes (OLEDs) have been realized using the thin alkali compound films (TACFs) at the interface between an emitting layer and an electron transporting layer with conventional organic layers. By comparing the performance of the device as a function of position with the TACFs, we propose the optimal position of the TACFs in the tris-(8-hydroxyquinoline) aluminum (Alq3). A device with the TACFs showed high luminance of over 12 500 cd/m2, luminance efficiency of more than 12 cd/A, and power efficiency of more 4.5 lm/W, respectively.

1. Introduction

To date, organic light-emitting diodes (OLEDs) have attracted considerable attention due to their potential application in mobile, large-area, and full-color flat-panel displays [1], [2]. However, the electric performance and the stability of OLEDs remain lower than commercial inorganic semiconductor light-emitting devices [3]. In result, to improve the performance of OLEDs, it is important to balance the number of holes and electrons injected into an emitting layer (EML) to archive a high level of recombination efficiency. In tris-(8-hydroxyquinoline) aluminum (Alq3) - based OLEDs that simultaneously use an EML and an ETL, the initial electron-hole recombination is generated near the hole transport layer (HTL) and the EML interface, and then the injected hole diffuse from the EML into the ETL. Finally, light is generated by a direct electron-hole recombination inside the ETL because of different levels of electron-hole mobility and density [4], [5]. So, to improve the carrier balance, the optimized recombination zone in which electron-hole pairs take place is necessary.

In this study, we present the characteristics of highly efficient and bright OLEDs with the thin alkali compound films (TACFs) between an EML and an ETL with conventional OLED structure without doping process. To define a recombination zone, we use the thin alkali compound films (TACFs), such as lithium fluoride (LiF) and cesium fluoride (CsF). This concept is based on the assumption that the HOMO level of Alq3 is lowered by band bending, and then, the lowering of the HOMO level is accompanied by the lowering of the lowest unoccupied molecular orbital (LUMO) level [6]. It enhances the electron injection, carrier balance, and recombination efficiency by lowering electron injection barrier height. Because the performance of the device depends on the position of the TACFs in the Alq3, we sought the optimal position in which the TACFs improve the performance of OLEDs.

2. Results

To optimize the thickness of an EML, the configuration of the devices studied was ITO / Copper Phthalocyanine (CuPc) / [N,N`-di(naphthalene-1-yl)-N,N`-diphenyl-benzidine] (a-NPD) / Alq_3 / TACFs / Alq_3 / LiF / Al with an emitting layer thickness varying from 0 ~ 50 nm. The total thickness of Alq_3 is fixed on 60 nm and an emitting layer defined by insertion the TACFs in Alq_3. We use a LiF and a CsF as the TACFs in this work. The HOMO and the LUMO levels of a-NPD are reported as 5.7 eV and 2.6 eV and CuPc as 4.8 eV and 3.1 eV, respectively. The CuPc layer in contact with ITO is an anode buffer layer used to facilitate holes injection. A thin LiF interlayer between Al cathode and Alq_3 improve the device performance from an electron injection barrier lowering caused by a lowering of the LUMO level in the Alq_3 layer. The TACFs have been inserted to optimizing an EML in which electroluminance take place and to improve the carrier injection and recombination efficiency for obtaining high performance OLEDs. Table 1 shows the structures of each layer and the position of the TACFs in Alq_3 and the performances of the fabricated devices. The devices B to D are using the LiF layer as the TACFs, and the device E with an EML of 10nm is using the CsF as the TACFs.

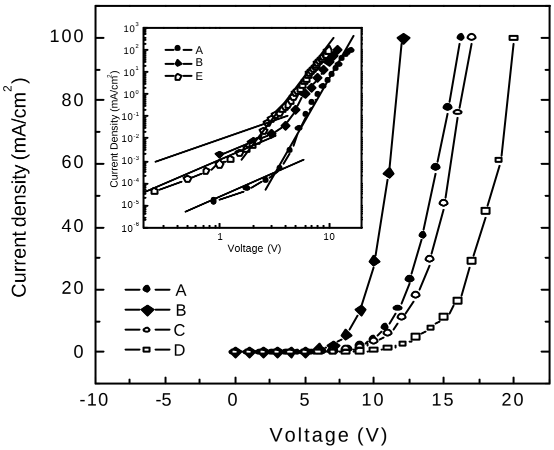

Figure 1. Current density vs. voltage characteristics of the devices. Inset: comparing the devices with TACFs and control device

Figure 1 shows the current density (J) vs. driving voltage (V) with the structure of the organic layers by insertion of the thin LiF layer as the TACFs between an emitting layer and an electron transport layer. The J-V characteristics are extremely sensitive to the thickness of an emitting layer and an electron transport layer. The driving voltage for the device B, lower than device A. The device B, especially, with an emitting layer of 10 nm requires a driving voltage of approximately 10 V to generate a current density of 100 mA/cm^2 and turn-on voltage is measured around 3.0 V at 1 cd/m^2. However the emitting layers more increased than device B, the driving voltage are increased than device A at same current density. Also, the J-V characteristics of device E with emitting layer of 10 nm has been similar to the device B. We infer that the device with 10nm of an emitting layer, and 50 nm of an electron transport layer, has the highest carrier transporting of electron injected into emitting layer among fabricated devices (Seeing the inset).

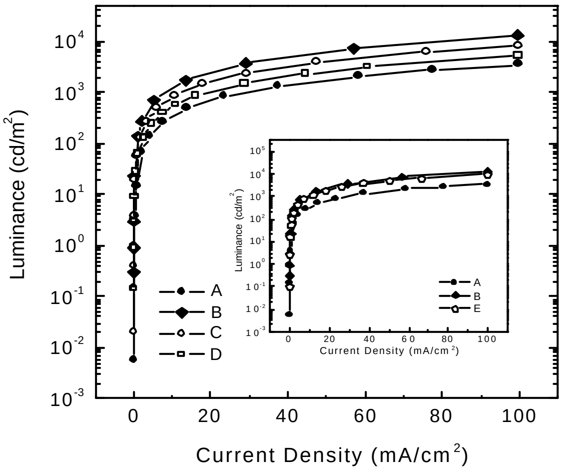

Figure 2. Luminance vs. current density characteristics of the devices. Inset: comparing the devices with TACFs and control device

The luminance increases linearly along with the current density for all the devices as shown in figure 2. The devices to have the recombination zone by insertion the TACFs have shown in high brightness performance. At the same current density, the luminance of the devices achieves its highest point in device B, and decreases in turn when the thickness of an emitting layer thicker than 10nm. Among fabricated devices, the device B achieves a 12 790 cd/m^2 at 100 mA/cm^2 and attains a brightness of 1 000 cd/m^2 at only 10mA. The device E also more improved a luminance than control cell as shown in the inset of figure 2.

Similar results can be found in figure 3 and inset, in which luminance efficiency-current density curves as an illustration of a function of the OLEDs with different thickness of an EML are exhibited. The luminous efficiencies of the B ~ E with recombination zone using the TACFs are 12.8, 8.1, 5.2, and 9.5 cd/A, respectively, at 20mA/cm^2. For comparison, the luminance efficiency of the control device measures only 3.5 cd/A (Seeing the Table I.). Therefore, we conclude that the optimum thickness of a recombination zone for improving a carrier balance and electron injection to archive the high level of recombination efficiency is 10 nm of an EML.

	Layer structures							Performances			
Cell No.	HIL (nm)	HTL (nm)	EML (nm)	TACFs (nm)	ETL (nm)	LiF (nm)	Cathode (nm)	Turn-on Voltage (V)	Luminance at 100 mA/cm^2 (cd/m^2)	Luminance efficiency at 20 mA/cm^2 (cd/A)	Power efficiency at 1000 cd/m^2 (lm/W)
A	3	30	0	0	60	1	120	6.1	3 500	3.5	0.8
B[a]	3	30	10	1	50	1	120	3.0	12 790	12.8	4.6
C[a]	3	30	30	1	30	1	120	6.3	8 090	8.1	2.0
D[a]	3	30	50	1	10	1	120	8	5 190	5.2	0.9
E[b]	3	30	10	1	50	1	120	3.25	9 500	9.5	4.5

Table I. The layer structures and performances of the test cell with different thickness of an EML using TACFs.

[a] The devices have been used a LiF layer between an EML and an ETL as the TACFs.

[b] The device has been used a CsF layer between an EML and an ETL as the TACFs.

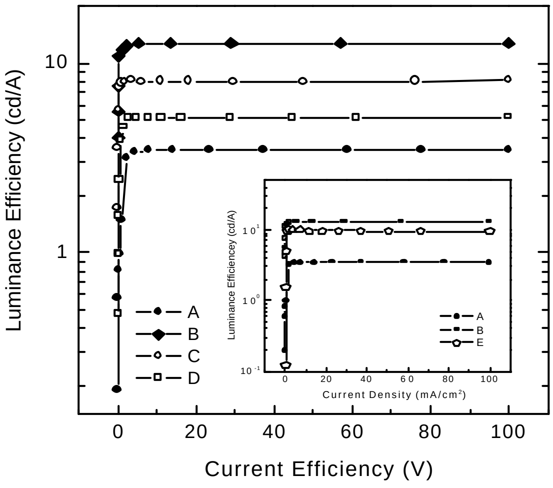

Figure 3. Luminance efficiency vs. current density characteristics. Inset: comparing the devices with TACFs and control device

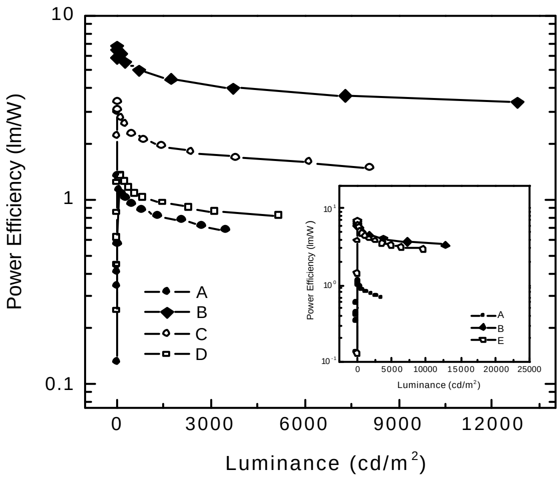

Figure 4. Power efficiency vs. luminance characteristics of the devices. Inset: comparing the devices with TACFs and control device

As shown in figure 4, the power efficiency is improved as well for the devices using the TACFs. Similar the luminous efficiencies characteristic, the power efficiency of the device B has the highest value than other devices. Also, device E has a high value of power efficiency (4.5 lm/W at 1000 cd/m^2) as shown in inset of figure 4. However, thickness of the emitting layer is increased than 10 nm, the power efficiencies have been decreased. We have summarized the performance of our test cell in Table I. The result shown that the carrier injection and recombination efficiency have been decreased more increased thickness of the emitting layer than 10 nm, but the efficiency of our devices higher than the control device. According to our experiments, the device B shows the highest luminous efficiency among the devices so the optimum thickness of an emitting layer and an electron transport layer are 10 nm and 50 nm.

3. Conclusion

Our fabricated devices show higher luminous and efficiency than other groups using Alq_3 devices (Seeing the Table I). A simple TACFs layer in Alq_3 to define the recombination zone to take place the emission improves the carrier balance for high recombination efficiency of OLEDs as shown in our results. Therefore, the TACFs can efficiently control the hole-electron balance for achieve high recombination efficiency in an EML and this technique may be applied to improve the efficiency and brightness of other OLEDs to have multi layer structure. This simple layer has allowed us to fabricate high performance OLED using inexpensive and easy way. So, the TACFs are good for the high performance and efficiency OLEDs and utilized to fabricate OLEDs.

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