# The Improvement of Luminance Efficiency by the Insertion of Buffer layers in Flexible Organic Light-Emitting Diodes

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#### **1. Introduction**

The successful development of organic light emitting diodes (OLEDs) in1987 [1] has attracted the attention and efforts of a considerable number of researchers into the field since. A few topics of interest, for example, how to enhance the luminance efficiency and improve ITO/organic adhesion, are particularly important for flexible OLED (FOLED). In the study of anode of FOLED, LiF [2], CuPc [3], Pani:PSS [4-5], and PEDOT:PSS [4-6] have been employed as buffer layer to enhance hole injection efficiency. The process for depositing thin film of Pani:PSS or PE-DOT:PSS by spin-coating results in smoother surface than that by thermal evaporation and hence improves the adhesion of organic material, which directly affects the flexibility of FOLED. In this study, PEDOT:PSS and TPD (first dissolved in CHCl<sub>3</sub>) are coated on ITO surface as the buffer layer of FOLED to improve the luminance efficiency of device.

#### 2. Experiments

## PEDOT: PSS as buffer layer

Cleaning the pre-patterned ITO by  $O_2$  plasma, the ITO was coated on the PET substrate (ITO sheet resistance  $50\Omega/\Box$ ). PEDOT:PSS (Baytron Al4083) was diluted with DI water and then spin-coated it onto PET/ITO substrate under 4500rpm. The PEDOT:PSS film was dried at 110°C for one hour to remove excess moisture and enhance film adhesion.

## TPD or α-NPD solved in CHCl<sub>3</sub> as buffer layer

Chloroform (CHCl<sub>3</sub>) was added to TPD or  $\alpha$ -NPD. Ultrasonically vibrate the mixture for 40 minutes to accelerate the dissolution and then spin-coated the solution at 0.4wt% concentration onto cleaned PET/ITO substrate under 4500 rpm. The resulting TPD or  $\alpha$ -NPD had a thickness of about 35 nm.

After the coating of buffer layer, place the substrate in organic evaporation chamber to deposit Teflon, NPB, and AlQ<sub>3</sub>, respectively, and then LiF and Al as cathode. The component parameters of devices and their respective thickness are shown in Table I. Computer-controlled KEITHLEY 2400 and SpectraScan PR650 were used to measure the L-I-V curves of devices.

#### 3. Results and Discussion

#### PEDOT:PSS as buffer layer

By comparing the characteristics of Device A and B as

shown in Fig. 1 and Fig. 2, it was found that the luminance and luminance yield of Device B with 40nm PEDOT:PSS as buffer layer are higher than those of Device A without PEDOT:PSS layer. The measurement of atomic force microscope (AFM) shows that the average surface roughness (Ra) of ITO dropped from 2.768 nm to 1.415 nm after the coating of PEDOT:PSS, which helped improve the formation of NPB film and device performance.

It was found that deposited 1nm Teflon following the coating of 80nm PEDOT:PSS as in the case of Device C further enhances the luminance efficiency of device. As shown in Fig. 1 and Fig. 2, Device C exhibited better luminance and yield than Device A and B. This is because Teflon can reduce driving voltage and enhance luminance efficiency [7]. If the thickness of AlQ<sub>3</sub> was increased to 100 nm as in the case of Device D, it is found in Fig. 1 and Fig. 2 ( $\star$  curves) that the luminance and yield of the device would increase to 2041 cd/m<sup>2</sup> and 6 cd/A respectively. This is because thicker AlQ<sub>3</sub> increases the area of electron-hole recombination, than enhanced the luminance and luminance yield of device.

## TPD or $\alpha$ -NPD solved in CHCl<sub>3</sub> as buffer layer

This study also examined the use of TPD in CHCl<sub>3</sub> as buffer layer material. This study coated consistently 35nm TPD in CHCl<sub>3</sub> onto the substrate, followed by the deposition of NPB and AlQ<sub>3</sub>, and attempted to obtain optimum device performance by varying the thickness of NPB and AlQ<sub>3</sub>. As shown in Fig. 3, Device E (with 35nm TPD in CHCl<sub>3</sub> and 40nm NPB) performed better than Device A which did not have TPD in CHCl<sub>3</sub> present. This is because the surface spin-coated with TPD in CHCl<sub>3</sub> was smoother than ITO, which enhances the film formation of NPB and effectively lowers the driving voltage of device. In addition, TPD in CHCl<sub>3</sub> could decrease the number of holes injected that allows the number of electrons and holes injected into the organic layer to reach equilibrium and hence enhances the luminance efficiency of device. If the NPB thickness was dropped to 20nm as in the case of Device F, the resulting luminance and yield were higher than those of Device E as shown in Fig. 3 ( $\blacktriangle$  curves). This is because reduced NPB thickness could shorten the distance of holes to AlQ<sub>3</sub> and increase the number of recombined electron-hole, thereby enhancing luminance. Also with the two carriers existing in equilibrium, the luminance yield of Device F could be maintained around 4 cd/. If the thickness of AlQ<sub>3</sub> was further increased to 80 nm (Device G), the luminance and yield of the device could reach  $2000 \text{ cd/m}^2$  and 4.3 cd/A

respectively. This is because thicker  $AlQ_3$  increases the area of electron-hole recombination, which enhances the chance of recombination and hence the luminance and yield of the device.

The study used  $\alpha$ -NPD with higher Tg (95°C) as buffer layer material in the preparation of Device H, which was coated with 35nm  $\alpha$ -NPD in CHCl<sub>3</sub>, followed by the deposition of 20nm NPB and 80nm AlQ<sub>3</sub>. Because  $\alpha$ -NPD has higher Tg than TPD and better holes transport performance, Device H exhibited better luminance and luminance yield than device coated with TPD in CHCl<sub>3</sub> as shown in Fig. 3 ( $\bigstar$  curves), which could reach 1070 cd/m<sup>2</sup> @ 20mA/cm<sup>2</sup> and 5.57 cd/A @ 12.6 mA/cm<sup>2</sup> respectively.

#### 4. Conclusions

This study successfully demonstrated the fabrication of flexible OLED (FOLED) displaying high luminance and high yield by spin-coating a layer of PEDOT:PSS, Teflon and TPD, or  $\alpha$ -NPD in CHCl<sub>3</sub> as buffer layer. When the thickness of PEDOT:PSS, Teflon and AlQ<sub>3</sub> was respectively 80 nm, 1 nm and 100 nm, and NPB was 40 nm, the device could reach maximum luminance of 2041cd/m<sup>2</sup> @ 10 V and its luminance yield could be maintained at  $\geq 6$  cd/A @ 1.0 ~ 27.4 mA/cm<sup>2</sup>. When the thickness of TPD in CHCl<sub>3</sub>, NPB and AlQ<sub>3</sub> was respectively 35 nm, 20 nm, and 80 nm, the device could reach maximum luminance of 2000cd/m<sup>2</sup> @ 8.5 V and its luminance yield could be maintained at  $\geq 4$  cd/A @ 5.6 ~ 32.1 mA/cm<sup>2</sup>. If TPD was replaced by  $\alpha$ -NPD, the luminance yield of device could be increased to  $\geq 5.5$  cd/A.

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		Table I Device Parameters				(unit: nm)		
Device No.	PEDOT:PSS	TPD in CHCl <sub>3</sub>	α-NPD in CHCl <sub>3</sub>	Teflon	NPB	AlQ <sub>3</sub>	LiF	Al
А	0	0	0	0	40	60	0.5	80
В	40	0	0	0	40	60	0.5	80
С	80	0	0	1	40	60	0.5	80
D	80	0	0	1	40	100	0.5	80
Е	0	35	0	0	40	60	0.5	80
F	0	35	0	0	20	60	0.5	80
F	0	35	0	0	20	60	0.5	80
G	0	35	0	0	20	80	0.5	80
G	0	35	0	0	20	80	0.5	80
Н	0	0	35	0	20	80	0.5	80



Fig. 1 Luminance vs. current density of devices with PEDOT: PSS and Teflon as buffer layer.



Fig. 2 Luminance yield vs. current density of devices with PE-DOT:PSS and Teflon as buffer layer.



Fig. 3 Luminance yield vs. current density of devices with TPD or  $\alpha$ -NPD in CHCl<sub>3</sub> as buffer layer.