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Effects of thickness of organic and multi-layer anode on luminance efficiency in top-emission organic light-emitting diodes

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1. Introduction

The top emitting Organic light emitting diodes (TEOLEDs) can be fabricated on opaque substrates, such as Si[1]. If they are applied to the active matrix OLED displays, the aperture ratio of each pixel can be increased. To fabricate the TEOLEDs, a high reflectivity anode should be fabricated firstly. The anode also need to have a high work-function to enhance the hole injection into the organic layer. Many researchers chose high work function metal as anode, such as C. F. Qi et al used Pt [2], C. J. Lee et al used Ni [3]. C. C. Wu et al employed Ag as the anode. But due to the low work function of Ag, a UV ozone surface treatment was carried out on the Ag surface to generate a thin AgO layer which has higher work function than Ag [4]. Some other researchers employed transparent ITO over the high reflectivity metal as the anode to achieve the top-emitting devices, Al/ITO [5], Ag/ITO[6]. In this work, the Al/Au bilayer was used as the anode to have high reflectivity and high hole-injection amount. And the LiF/Al/Ag multilayer was employed as the cathode. Optimum thickness parameters for anode and organic multilayers were studied to achieve the optimum emission characteristics.

2. Experiments

The device was fabricated on glass substrate, and the luminance area was set at 0.36 cm^2. The glass cleaned with O_2 plasma before being placed into a vacuum evaporation chamber. The anode Al/Au bilayer were evaporated with a shadow mask to defined patterns. The evaporation rate for Al and Au was 0.2 and 0.02 nm/sec, respectively. Next, the device was moved to another vacuum chamber for organic deposition of 4,4',4"-tris(N-3-methylphenyl-N-phenyl-amino)-triphenylamine (m-MTDATA) *N,N'*-dipheny -*N,N'*-bis (1-naphthyl)-(1,1'-biphenyl) -4,4'-diamine (NPB) and tris(8-hydroxyquinoline)aluminum (Alq3) are HIL, HTL and ETL, respectively. Finally the device was moved back to the metal evaporation chamber to deposit LiF/Al/Ag multilayers in sequence as the cathode with evaporation rate of 0.01, 0.05 and 0.05 nm/sec, respectively. The SpectraScan PR650 was employed for automatic measurement of luminance, and Keithley 2400 for automatic measurement of current-voltage characteristics.

3. Result and discussion

First the Al/Au bilayer anode structure, the thickness of the Al layer was varied from 35, 70 to 80 nm, while the thickness of Au was fixed at 5 nm, as the devices a, b, and c listed in Table 1, respectively. These three devices still employ LiF/Al/Ag as the cathode whose thicknesses were fixed at 0.2/4/15 nm. Figures 1 compare the luminance yield versus current, of the devices a, b and c. When the Al thickness used in Al/Au bilayer anode is 35 nm only, the top emission efficiency is very small, because a very thin Al layer becomes semi-transparent that passes some of OLED emission through the bottom side. So the light emitting to the top side becomes weak. When the Al thickness increases to 70 nm, the brightness of top emission increases much more because of more reflection from the bottom Al/Au anode to the top side. In Fig. 1, the Al/Au anode with 50/5 nm thickness also shows the maximum luminance efficiency. When the Al thickness further increases to 80 nm, the top emitting brightness decreases to lower than those of 70 nm. This is due to of that a thick Al deposition gives rise to a rough surface and thus decreases the reflectivity of bottom Al/Au anode.

The effects of thicknesses of hole injection and transport layers on the luminance characteristics were studied. As shown in Table 1 for devices d-g, the total thickness of hole injection and transport layers was fixed at 60 nm. The thickness of m-MTDATA (HIL) increased from 5 to 30 nm for device d to g, followed by NPB (HTL) decreasing from 55 to 30 nm. The hole injection efficiency increased and luminance efficiency increased to 1.4 cd/A when the m-MTDATA thickness increased from 5 to 20 nm [7], as chow in Fig. 2. But if the m-MTDATA thickness further increased to 30 nm and NPB decreased to 30 nm (device g), the hole injection efficiency become saturated. As know, the hole mobility of m-MTDATA is smaller than those of NPB. So too thick a m-MTDATA will deteriorate the hole transport mobility which gave rise to a carrier unbalance between hole and electron in the NPB/Alq3 interface. So the luminance efficiency decreased when m-MTDATA thickness further increased from 20 to 30 nm. The effects of thickness of electron transport layer on the luminance characteristics were also studied. As shown is Table 1 for devices h-g, the optimum luminance efficiency over 3 cd/A was obtained at Alq3 = 60 nm. When the ETL thickness increased (from 50 to 60 nm), there is long enough distance for excitons to diffuse which let excitons have large enough space to relax the energy by light-emitting. So the thick enough ERL can decrease the quenching effects near the

cathode interface and increase luminance efficiency [7]. But further increase in the ETL thickness will increase the turn-on voltage due to too long distance for electrons to transport and arrive the NPB/Alq3 interface to recombine with holes. So the luminance efficiency was decreased, as shown in Fig. 3. Figure 5 shows the compare of luminance efficiency different top emitting electrode structures as can be found from the references. Our works obtained a very high efficiency just lower than those of C. C. Wu[4].

4. Conclusions

In this study, multi layer anode structures were studied. To use Al/Au multi-layer as anode for top-emitting OLED is the first report in the literature. The Al/Au with optimum thickness of 70/5 nm have high reflectivity and high hole injection efficiency. The thickness of HIL, HTL and ETL were also adjusted (m-MTDATA/NPB /Alq3 of 20/40/60 nm) to balance the electron and hole carrier recombination ratio. A highest brightness and best luminance efficiency of 8041 cd/m^2 and 3 cd/A, respectively.

References

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Table 1 Structures for each device.

#	Anode (nm)		HIL (nm)	HTL (nm)	ETL (nm)	cathode (nm)			Max. (cd/A)
	Al	Au	m-MT	NPB	Alq3	LiF	Al	Ag	
a	35	5		60	50	0.2	4	15	0.3
b*	70	5							1.85
c	80	5							0.77
d	70	5	5	55	50	0.4	4	15	0.52
e			10	50					1.11
f*			20	40					1.4
g			30	30					0.88
h	70	5	20	40	50	0.4	4	15	1.4
i*					60				3
j					70				2.43

* optimum in each group

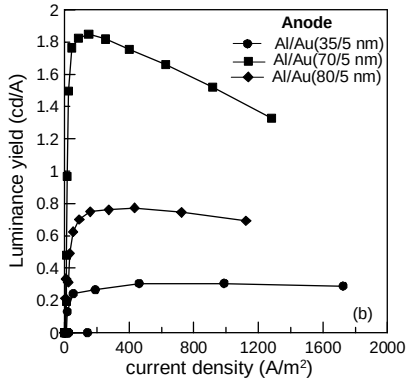

Fig. 1 Luminance versus current density of devices a,b and c, respectively.

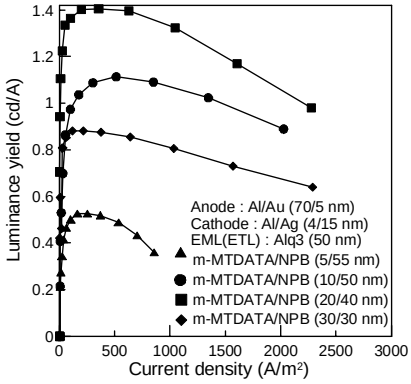

Fig. 2 Luminance versus current density of devices d, e, f and g, respectively.

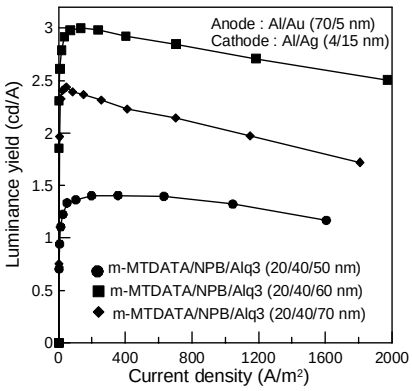

Fig. 3 Luminance versus current density of devices h, i, and j, respectively.

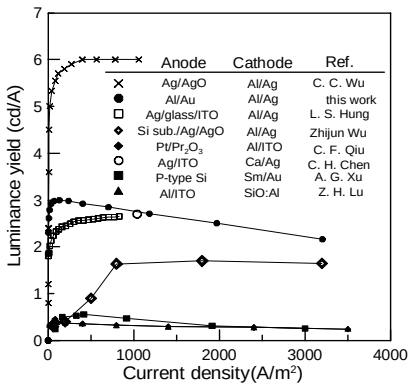

Fig. 4 compareisons of luminance efficiency for different top emitting electrode structures reported in TEOLEDs.