Study on optimal elctrode's thickness at passive OLED on power consumption

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Abstract - "CRT" which had dominated the market of display until 2000 is not appropriate for information indicating media due to several limitations.
Thus, TFT-LCD, PDP, OLED, etc are growing in display industry instead of CRT because they meet demands of information indicating media.
OLED display which responses within 1ms fits any picture manifestation medias because it uses self radiance OLED for picture element that has no obstacles in showing the angle of vision.
OLED's characteristic of action is very sensitive to thickness of electrode so that this has been an important issue.
This study tried to find the most suitable thickness of electrode using ITO, Mo, and AL. Using the results of IVL measurements, analyzed equality of electrode board. As a result, found the thickness of electrode that has high electrical efficiency and optimized it.

1. Introduction

Nowadays people are getting interested in OLED(organic light emitting diode) since its performance has remarkably improved for application in flat panel display since 1987[1].
OLED have been shown to have sufficient brightness, range of color and operating lifetimes for use as a practical alternative technology to LCD based full-color flat-panel display. Furthermore, oled also have very fast response time, enabling a simple matrix addressing to be effectively used even for displaying fast moving pictures. But, there still remain each pixel current for driving and full-color problems.
The ideal oled must have lower power, high uniformity and higher contrast ratio for the full color to be used effectively. The basic structure of the OLED, shown in Fig. 1, has not changed substantially since first demonstration of its high efficiency and low voltage electro-luminescence (EL) from an organic thin film.
A multi-layer structure consisting of hole transport layer, emission layer and electron transport layer allows to achieve bright electro-luminescent emission in the visible spectral region at low driving voltages. Fig. 2 describes so called barrier ribs in panel structure[2].
Each layer was deposited by vacuum evaporation method under vacuum of < 10^{-5} Torr.
The first layer consists of a hole transporting material such as N, N'-diphenyl-N, N-bis(3-methylphenyl)1-1'-biphenyl-4, 4'-diamine (TPD), and the second of a light-emitting, electron transporting material such as tris-(8-hydroxyquiniline) aluminum (Alq_3)[3].
The top, electron-injecting electrode typically consists of

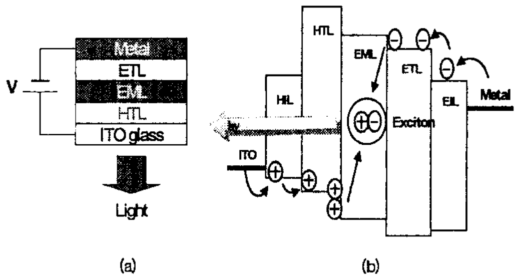

Fig. 1. (a) Typical device architecture of OLED

Mg-Ag or Li-Al. The bottom, hole-injection electrode typically be composed of a thin film of transparent semiconductor indium tin oxide (ITO).
Light is emitted through this electrode when ITO is biased positive with respect to the top electrode. It was discovered that degradation of OLED's occurs in air on a time scale of a few hours. Charge conduction in these ostensibly insulating organic electro-luminescent materials requires electric fields typically in the range of active 2~5MV/cm. Such operating conditions, coupled with a reactive, low work function top electrode which is required to ensure efficient injection of electrons into the organic shown that even simple encapsulation in an insert atmosphere, using an epoxy-sealed glass package for example, can extend the useful device lifetime[4]. Also, remaining degradation modes after encapsulation include the formation and growth of non-emissive "dark spot defects." With small particle and scratch on the surface through sputtering process, the spikes and bulk bring about significant decrease of resistance and then the path to leak current sharply[5~6]. Also, the thickness of ITO film on glass substrate is one of the important methods to build up reliability and performance of the panel. The electrode in OLEDs has been reported as an important factor to influence the electrical and luminescent properties.
The optimal thickness of the various constituent oled electrode has been identified and discussed.

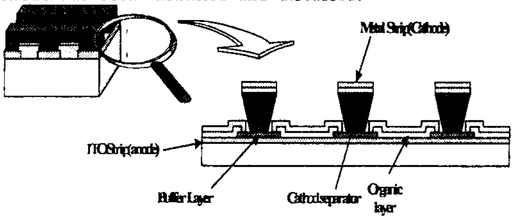

Fig. 2. Cross-sectional view of a passive OLED.

2. OLED's design

We have developed passive matrix of 1.98-in. Average brightness and resolution of the sample panel are 50cd/㎡ and 120 × 160, and it drives with PWM and PFM. We developed a sample module that scanning duty-ratio is available to select freely. But average scanning duty is 1/60 cycle Stack type column of anode pattern was formed in the active area by conventional photo-lithography technique. Before cathode separators are formed, a series of organic layers are formed on the top of ITO by the vapor deposition in vacuum. Eventually, the organic layers were thermally deposited on the substrate with ITO film. Glass size is the 33.4×47.1(mm). The deposed Al sealing line is 0.38(mm). Dot pitch is 0.226×0.255(mm).

We fabricated a stack type panel under standard condition[ITO 1500Å,Mo 2600Å, Al 1500Å]. We changed the thickness of electrodes such as ITO, MO and Al.

3. Effects of anode, bus and cathode electrode thickness

In order to exactly measure the thickness of electrodes, we used probe-station. Data-line resistance and scan-line resistance was measured by probe-station. The thickness of ITO, Al and Mo electrodes are [ITO: 1000 to 1500Å, Mo: *700 to 2600Å and Al; 1000 to 1500Å*].

With it sees from table 1, the condition 1 is standard condition. The highest resistance is obtained from condition 3. The dominant factor is the Mo thickness(see table1). Shown in Fig. 3 is a contour plot of data and scan resistance value. As the Mo thickness was changed 2600Å to 700Å, its resistance was increased to 84%. The ITO thickness hardly have an effect on data-line resistance. When the ITO thickness has diminished from 1500Å to only 1000Å, data-line resistances have barely increased 6%. As we examined so far, the Mo thickness is the main factor which gives an effect to resistance not only data-line but also even scan-line. The same figure also shows scan resistance characteristics when the Mo thickness decreased. In other words, the data-resistance and scan-resistance depend on Mo thickness.

On the other hands, the effect of ITO and Al are scarcely influenced by scan-line resistance of oled's panel.

condition	Test thickness			Thickness measured by SEM(ITO basis)			Data Resistance (kΩ)	Scan Resistance (Ω)	remark
	ITO(Å)	Mo(Å)	Al(Å)	ITO(Å)	Mo(Å)	Al(Å)			
1	1500	2600	1500	1500	2590	1740	6.6	159	Standard
2	1500	2600	1000	1500	2530	880	6.7	144	
3	1500	1600	1500	1500	1345	1580	11.52	181	
4	1500	700	1500	1500	765	1530	12.35	270	Maximum Resistance
5	1000	1500	1000	1000	975	885	11.6	208	
6	1000	2600	1500	1000	2460	1465	7.1	159	

Table 1. *Electrode thickness in samples measured by* Probe-station.

조건	Test thickness			Resistance increased in standard basis		Power increasement(mW)		Power consumption			
	ITO(Å)	Mo(Å)	Al(Å)	Data resistance (kΩ)	Scan resistance (Ω)	50μA basis	250μA basis	Mode A (mW)		Mode B (mW)	
2	1500	2600	1000	0.1	-15						
3	1500	1600	1500	4.92	25	25	635	Designed value	Observed value	Designed value	Observed value
4	1500	700	1500	5.75	111	82	2057				
5	1000	1500	1000	5	44	38	938	220	340	1300	-
6	1000	2600	1500	0.5	0	1	23				

Table 2. Power consumption caused by bus-line resistance.

4. Effects of power consumption

In table 2, as the thickness of the bus-line(Mo) electrodes came to be thin, the power consumption becomes more and more increasing. When one pixel current is flowing 250[μA], maximum is 2057[mW] and minimum is 23[mW]. The maximum is increased by 150% from 23[mW]. Power consumption rate by the thickness of bus-line electrode(Mo) shown in Fig. 4 is a major factor to optimize line current toward column direction when driving. We calculated voltage drop.

We obtain(condition 4),

data line - Red : $250[\mu A]\times 10^{-6}\times 5.75[k\Omega]\times 10^{3} = 1.44[V]$

Green : $250[\mu A]\times 10^{-6}\times 5.75[k\Omega]\times 10^{3} = 1.44[V]$

Blue : $250[\mu A]\times 10^{-6}\times 5.75[k\Omega]\times 10^{3} = 1.44[V]$

scan line $-(250+250+250)[\mu A]\times 120\times 10^{-6} 10^{-6}\times 111[\Omega]= 10[V]$

Also, Maximal power increasement is,

$\{(250\times 1.44+250\times 1.44+250\times 1.44)[\mu A]\times 10^{-6}\times 120\times 2\}(\text{data-line})+\{(250+250+250)[\mu A]\times 10^{-6}\times 120\times 2\times 10[V](\text{scan-line}) = 2057[mW]$

As you can see, in condition 2, the scan-resistance in panel is observed to reduce the resistance of the scan-electrode after the thickness of Al electrode becomes thin(see Table 2). The reason is that Mo and Al electrodes improve contact resistance. Therefore, the scan-line resistance is diminished. When reducing Mo thickness, the rate of power consumption is increasing rapidly. Due to the increased power consumption, it is too difficult to apply mobile

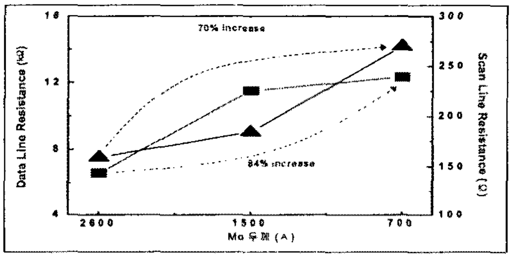

Fig. 3. Data-line resistance and scan-line resistance as a function of the Mo thickness.

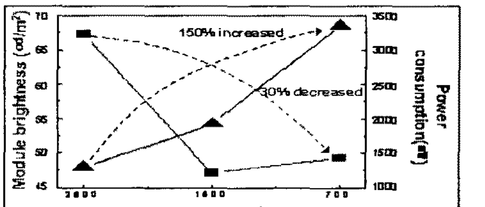

Fig. 4. Module brightness and power consumption as a function of the Mo thickness.

applications. However, this is applied to home appliance *such as refrigerator, air-conditioner and washing machine.*

As the Mo thickness was reduced from 2600Å to 700Å, the power consumption was changed from 1990[mW] to 3000[mW].

5. IVL characteristics results

Current-voltage(*I-V*) and luminance-voltage(*L-V*) characteristics were measured with Keithley source-measurement unit 236 and Yokokawa electronics *illuminance-Meter* 3298. We observed voltage(V) and current density(J) characteristics of the OLED device are summarized in Fig. 5(a). And, Fig. 5(b) shows the plots of the luminance versus current-density. In our study, the 1-1(see Fig.5) curve of peak shows that standard condition is only composed of ITO, Mo and Al electrode.

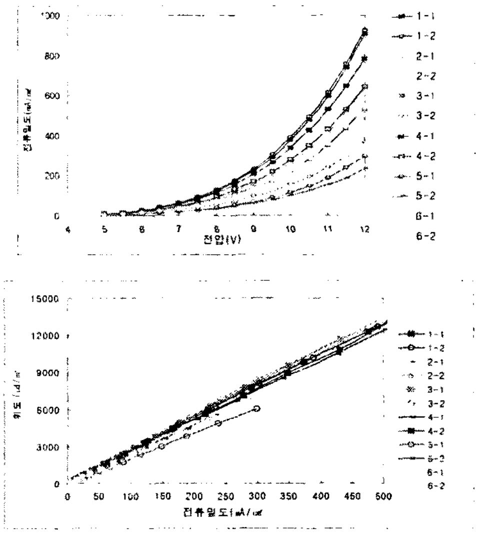

Fig. 5. (a) Current density-voltage characteristics of samples.
(b) Dependence of OLED Luminance-voltage characteristics of samples.

there is a slight curve at 510[nm] due to differences in the transparency by ITO thick. The 1-1 sample(standard panel) quantum efficiency is higher than the others. The *I-V* graphs a function of current-density of OLED with each electrode thickness is shown in Fig. 6(a). The more the resistance of panel's electrode is increased, the more *I-V* characteristic is bad. A luminescence characteristic of the OLED compared to that of a thick ITO electrode is shown in Fig. 6(b). This indicates that it depends on ITO thickness. Also, it is relatively independent of bus-line resistance.
The brightness of this sample device is 13,000 cd/m² at 10.8V with 481 mA/cm². In our IVL plots, it was confirmed that the best characteristic sample's standard condition[No1]. The reason why both *I-V* and *L-V* characteristics are simultaneously increased after optimizing is thought to be that the electrodes are very optimistic.
In addition, when module driving, the brightness is decreased by the increased line-resistance.
Fig. 8 shows the module brightness and the thickness of electrodes obtained by varying the pixel current from 50 [μA] to 200[μA].

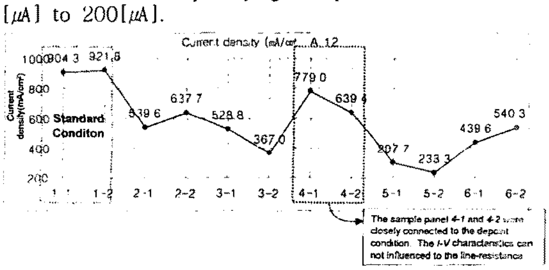

Fig. 6. Current density and brightness characteristic.

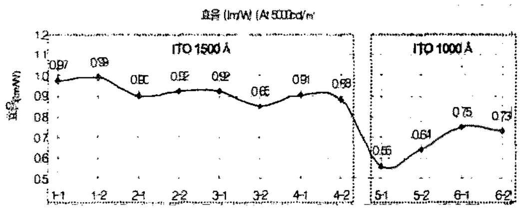

Fig. 7. Efficiency characteristic of OLED samples.

6. Results and discussion

We have shown that it was possible to improve the operating conditions of OLED through appropriate electrode thickness.
Furthermore, we have been proposed optimistic electrode thickness in 1.8" passive mobile applications. We figure out the most significant factor is Mo's thickness.
As a rsult, if there's problem with Mo's thickness reduction, it is impossible mobile application because of higher power consumption. However, it is applied to digital appliance air-conditioner, refrigerator, microwave and so on.
For optimal power efficiency and brightness, the thickness

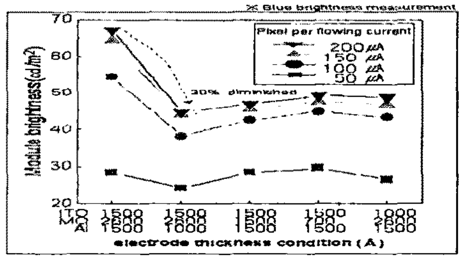

Fig. 8. Dependence of OLED Luminance(L)-electrode density characteristics on the pixel current.

of ITO, Mo, and Al are 1500(Å), 2600(Å), and 1500(Å), respectively. At these optimal configuration, a luminance of 13,000 cd/m² is obtained at a current density of 481 mA/cm².

7. References

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