

F-7-2

## Top-Emission Inverted Organic Light Emitting Diode Using Aluminum Nitride as Buffer Layer

Chien-Chang Tseng, Fuh-Shyang Juang, Tay-Shan Liu

Institute of Electro-Optical and Materials Science, National Formosa University, Yunlin, 632-08 Taiwan

TEL:+886-5-6315650 E-mail:fsjunag@seed.net.tw

### 1. Introduction

One of the trends in the OLED (organic light emitting diode) display industry in recent years is to develop large-screen display. Large-size panel must be driven by thin film transistor (TFT) to enhance its brightness uniformity, resolution and life time. The conventional OLED have predominantly bottom-emission structure where emitted light is partially blocked by bottom-layer TFT and data line. To improve aperture ratio and minimize the effect of TFT on active-matrix panel, the research and development of top-emission OLED is inevitable [1]. To integrate the process for OLED with other active components in the fabrication of active-matrix panel, including amorphous silicon ( $\alpha$ -Si), poly-silicon (Poly-Si) or complementary metal oxide semiconductor (CMOS), the whole process may be simplified if the electrode (Al pad) prepared on TFT substrate in the final step of the process is also used as the cathode of OLED. Such OLED device must employ top-emission inverted organic light emitting diodes (TEOLED) structure. Many researchers have proposed inverted top-emission light-emitting diode by inserting an ultra thin insulating layer between the organic layer and metal electrode to increase electron injection from cathode, thereby enhancing the luminance efficiency. For example, Li et al. [2], Kurosaka et al. [3] and KHO et al. [4] respectively inserted a proper buffer layer of  $\text{Al}_2\text{O}_3/\text{AlN}_x$  between the organic light-emitting layer and Al cathode to improve the electroluminescence of OLED. This paper utilized the plasma of Ar+N<sub>2</sub> gas mixture to treat Al surface to modify the surface roughness and form an ultra-thin AlN<sub>x</sub> insulating layer (or buffer layer) to improve the efficiency of cathode electron injection.

### 2. Experiment

Our experiment comprised the following steps: First ultrasonically wash the glass substrate with in sequence acetone, methyl alcohol and DI water. Deposit cathode metal Al on the glass substrate by evaporation under  $3 \times 10^{-6}$  torr and then move the substrate to a microwave plasma chamber to undergo plasma treatment of Al surface with the mixture of Ar (70sccm) and N<sub>2</sub> (10sccm) under 0.35 torr and 90W to form AlN<sub>x</sub> as buffer layer. Remove the AlN<sub>x</sub>-treated substrate from plasma chamber and place it in organic vacuum evaporator to deposit tris(8-quinolinolato) aluminum (AlQ<sub>3</sub>) as green-light emitting layer, NPB as hole transport layer, and m-MTDATA as hole inject layer (HIL). Finally move the substrate to another chamber to deposit Au/Ag as metal anode by evaporation. The resulting device has a structure of glass/Al(80nm)/AlN<sub>x</sub>/AlQ<sub>3</sub>(50nm)/NPB(60nm)/m-MTDATA(100nm)/Au(5nm)/Ag(10nm) as shown in Fig. 1. The light emitting area of the

device was  $36\text{mm}^2$  as defined by shadow mask. The experiment used KEITHLEY 2400 and SpectraScan PR650 to measure the L-J-V curve of device, atomic force microscope (AFM) and contact angle to observe its surface roughness, and four-point probe to measure the sheet resistance.

### 3. Results and Discussion

Atomic force microscope (AFM) was used to observe the surface roughness of Al cathode layer after microwave plasma treatment over different durations. As shown in Table 1, it is found that untreated Al electrode surface has many spikes that would cause non-uniform distribution of electric field in the organic layer during the operation of OLED and render the OLED prone to damage under higher current density. Thus prior to the deposition of organic film, Al electrode should undergo surface planarization with microwave plasma, which improves surface roughness significantly. Based on the measurement of contact angle, it is also clear that there is better adhesion between the plasma-treated Al electrode and the organic layer.

Fig. 3, Fig. 4 and Fig. 5 show respectively the J-V curve (current density vs. voltage), L-V curve (luminance vs. voltage), and  $\eta$ -V curve (yield vs. voltage) of the same device under plasma treatment of different durations. As shown by the J-V curve, the resistance of plasma-treated Al surface increased as treatment time increased, which led to decrease in current density as shown in Table 1. Based on the L-V curve in Fig. 4, it is found increase in the time of nitrogen treatment led to increase in threshold voltage. Untreated Al cathode caused organic layer to produce joule heat under higher current and same voltage and burn more easily. As shown in Fig. 4 and Fig 5, under optimum plasma treatment time of 40 seconds, the device obtained maximum luminance and yield of  $1206\text{cd/m}^2$  and  $0.51\text{cd/A}$  respectively under 17V. Device made of untreated Al electrode had extremely short life-time, while treated device with an AlN<sub>x</sub> buffer layer had significantly longer service life.

When plasma treatment time increased to more than 40 sec, the luminance and yield of device decreased gradually instead. It might be attributed to the fact that prolonged treatment time resulted in thicker AlN<sub>x</sub> and hence high resistivity, which makes injection of electron into AlQ<sub>3</sub> more difficult. The functions of AlN<sub>x</sub> may be summed up as follows: 1. Proper AlN<sub>x</sub> thickness aids the tunneling of electrons [5][6], for in the absence of AlN<sub>x</sub> as buffer layer, there exists a larger potential barrier at AlQ<sub>3</sub>/Al interface to block the injection of cathode electrons into AlQ<sub>3</sub>; 2. the mobility of surface electron in organic material is lower than that of hole, and AlN<sub>x</sub> can block the

circulation of holes to prevent quenching of exciton at AlQ<sub>3</sub>/Al interface.

In the TEIOLED structure discussed in this paper, Au(5nm)/Ag(10nm) was used for anode. The penetration rate of such double-layer anode was approximately 47%. In addition, change in the thickness of organic or metal electrode would cause displacement of emission peak in microcavity. In the example of changing the total thickness of organic layer, when the length of microcavity increased from 120nm to 210nm, emission peak shifted from 508nm to 552nm. The change in resonance wavelength is not just a result of change in microcavity length, but also due to difference in the reflection phase of top and bottom surface electrodes. It is clear that as the measuring angle increased, the peak of EL spectrum would drop from 576nm to 524nm to produce blue displacement phenomenon, mainly due to the intense microresonance effect [7].

#### 4. Conclusions

We have demonstrated that using the microwave plasma of Ar+N<sub>2</sub> mixture to treat the surface of Al electrode over the optimum treatment time of 40 sec can form an ultra thin AlN<sub>x</sub> layer as the buffer layer for injection of electrons from cathode. This surface treatment effectively improves the efficiency of electron injection, enable the number of electrons and holes injected to reach a balance and prevent the phenomenon of exciton quenching at the cathode, thereby significantly enhancing the luminance, efficiency and life-time of the device. The N<sub>2</sub>/Ar ratio and plasma treatment time were adjusted to obtain the maximum luminance and efficiency of 1206 cd/m<sup>2</sup> and 0.51 cd/A, respectively, both at 17 volts.

#### References

- [1] M. Kitamura, T. Imada and Y. Arakawa, Appl. Phys. Lett. **83** (2003) 3410
- [2] F. Li, H. Tang, J. Anderegg and J. Shinar, Appl Phys Lett. **70** (1997) 1233
- [3] Y. Kurosaka, N. Tada, Y. Ohmori and K. Yoshino, Jpn. J. Appl. Phys. **37** (1998) 872
- [4] S. Kho, S. Sohn D. Jung, Jpn. J. Appl. Phys. **42** (2003) 552
- [5] Z. B. Deng, X. M. Ding, S. T. Lee and W. A. Gambling Appl. Phys. Lett. **74** (1999) 2227
- [6] H. T. Lu and M. Yokoyama, Solid-State Electronics **47** (2003) 1409
- [7] A. Dodabalapur, L. J. Rothberg, R. H. Jordan, T. M. Miller, R. E. Slusher and J. M. Philips, J. Appl. Phys. **80** (1996) 6954

#### Acknowledgements

We like to thank the National Science Council for the funding of this project No. NSC 93-2215-E-150-008.

Table 1 Roughness, contact angle, resistivity of Al cathode, max. luminance and yield of TEIOLED under different plasma treatment time

Treatment time	Roughness (Ra,nm)	Contact Angle	Resistivity (Ω-cm)	Max. Luminance (cd/m <sup>2</sup> )	Yield (cd/A)
Untreated	5.249	22.30°	6.55×10 <sup>-8</sup>	418@14V	0.17@14V
40s	4.112	9.88°	7.40×10 <sup>-8</sup>	1206@17V	0.51@17V
60s	3.747	8.63°	7.51×10 <sup>-8</sup>	474@17V	0.29@16V
80s	2.551	7.32°	7.54×10 <sup>-8</sup>	256@17V	0.20@17V

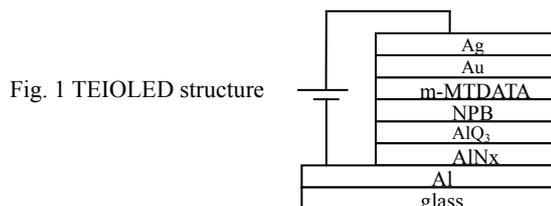


Fig. 1 TEIOLED structure

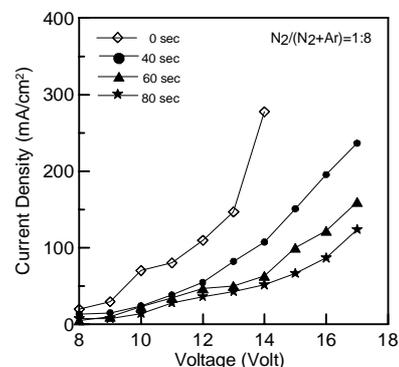


Fig. 3 Current density of TEIOLED vs. voltage under different plasma treatment time

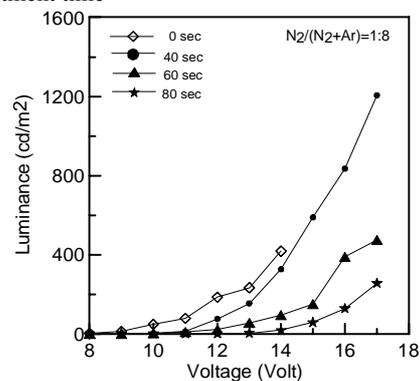


Fig. 4 Luminance of TEIOLED vs. voltage under different plasma treatment time

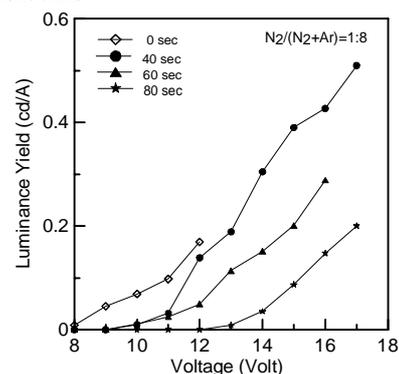


Fig. 5 Luminance yield of TEIOLED vs. voltage under different plasma treatment time