A Novel Strategy of Multi-layer Metal Electrode for Mini-LED Backlight Using 4-mask Process

Baolai Jiang[1], Junling Liu[1], Liangyi Cai[1], Zhiying Li[1], Qinzun Lin[1], Xianwang Wei[1], Yifeng Yang[1], Conglong Zhang[1]

jiangbaolai@tcl.com

[1]TCL China Star Optoelectronic Technology Co., Ltd. Guangdong, China

Keywords: mini-LED backlight, MoTi/Cu/MoTi layer, electrical properties, bond strength

ABSTRACT

Mini/Micro LED are highly desirable for next-generation consumer displays. However, the potential application of Mini/Micro LED are strongly hindered by their potential high-temperature damages after the LED surface mounting process. Herein, a new low-cost strategy for Mini-LED backlight with a 4-Mask process is reported, which used MoTi/Cu/MoTi 3-layer S/D electrodes structure to replace additional ITO layer. The electrical performance and bond strength of LED and chip on film(COF) of backlight system was comparable to those of 5-Mask Mini-LED backlight.

1 INTRODUCTION

The multi-zone local dimming mini-LED backlight are considered as a promising technology for realizing high contrast ratio (HDR), high peak brightness and excellent dark state of LCD display[1, 2]. However, the usual metal electrode, such as Al or Cu, is easily oxidized at high temperature during surface mounting process of LED and chip on film (COF) bonding [3], causing a dramatic increase of COF bonding connection resistance. In order to decrease influence of high temperature oxidation, a ITO layer was covered on the top of Cu or Al electrode. Although this strategy effectively avoid metal oxidation, the cost increases obviously because of an additional photo mask and ITO film. In this paper, instead of using an additional ITO film, a novel low-cost 4-mask strategy was proposed for mini-LED backlight system by using 3-layer MoTi/Cu/MoTi as Source/Drain (S/D) electrode.

2 EXPERIMENTS

The structure of device was shown in Fig.1a. A 550-nm-thick Cu film and 30-nm-thick Mo film were deposited on a glass substrate by DC magnetron sputtering and patterned by wet etching. Then a 520-nm-thick SiN_x gate insulator (GI) and 185-nm-thick a-Si active layer were deposited by PECVD at 360 ^oC and patterned with dry etching. After that, a 3-layer MoTi/Cu/MoTi source/drain (S/D) electrodes were deposited on active layer, their thickness were 20 nm, 550 nm and 30 nm, respectively.

The S/D electrode was patterned using half-tone mask (HTM) and a dry etch process. Next, a 100-nm-thick SiN_x passivation(PV) layer was deposited by RF magnetron sputtering at 285 °C, the PV layer was patterned by HTM photolithography and a dry etching, photo resistance was etched with traditional O_2 plasma, PV layer was etched with NF_3 and O_2 mixture, top MoTi layer was etched with BCl_3/Cl_2 mixture at 80 °C through inductive couple plasma(ICP) mode. Finally, LED was bonded on TFT substrate with solder paste by surface-mount technology, the reflow soldering temperature is 217 °C. IC chip was connected on bonding lead with anisotropic conductive film (ACF) at 300 °C . For comparison, as shown in Fig.1b, a 5-mask reference device was prepared whose no top MoTi layer and an additional 60-nm-thick ITO layer was deposited on passivation layer to prevent surface oxidation.

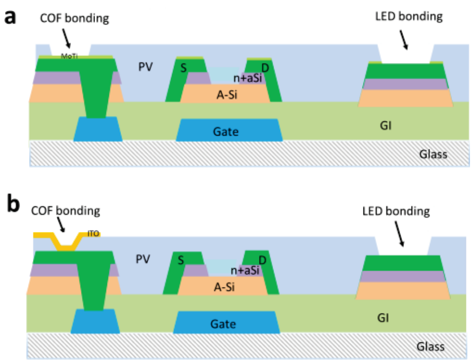

Fig.1 Schematic cross section of a mini-LED backlight TFT: (a) 4-Mask TFT, (b) 5-Mask TFT.

3 RESULTS AND DISCUSSIONS

The MoTi film exhibit excellent high-temperature oxidation resistance, as shown in Fig.2, no apparent change was observed on the surface of MoTi layer, however, there was a visible color difference from red to black which indicates the formation of an oxide coating. The EDS mapping analysis further prove formation of metal oxide, contents of oxygen element on Cu film significantly increased after heat treatment, implied forming of a metal oxide layer. Comparably, there are little changes in the distribution of O on the surface of MoTi film before and after heating treatment, which implied excellent oxidation stability of MoTi film.

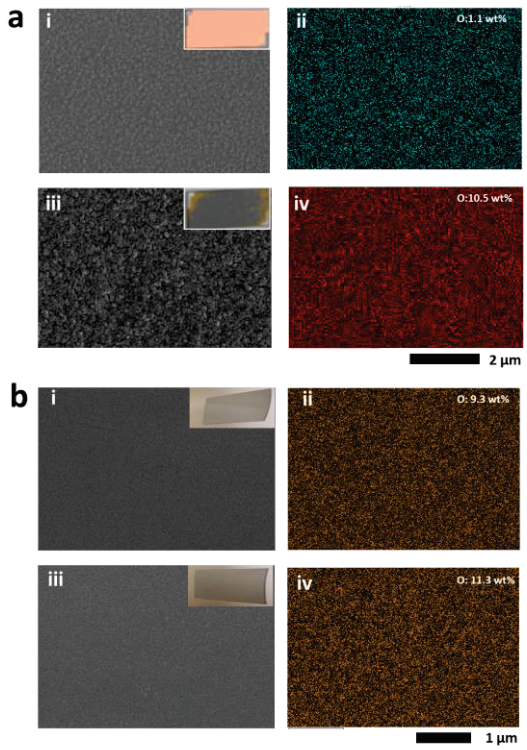

Fig.2 Scanning electron microscope images and EDS mapping of the surface O elements before (i, ii) and after (iii, iv) heating at 250 °C for 2 h: (a) Cu, (b) MoTi.

In measurement procedures of LED bonding process, we used bonding tester to estimate shear strength. As shown in Fig.3a, shear strength of LED when bonded on MoTi is lower than that of Cu. which due to worse adhesion between solder and MoTi layer, as shown in Fig.4, the solder peeled away from MoTi film, but bound tightly to Cu film after reflow soldering owing to Cu film good solderability characteristics[4]. So that is why the top MoTi layer of LED bonding zone need to be etched.

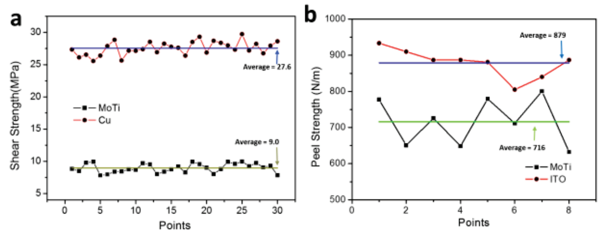

Fig. 3 (a) Shear bond strength of LED, (b) peel strength of COF bonding area.

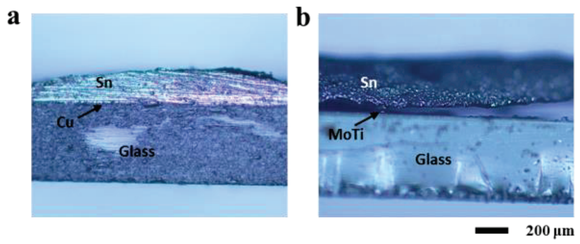

Fig. 4 Optical microscope images (a) Cu and (b) MoTi film after reflow soldering on cross-section views.

Chip-on-film (COF) package was attached on metal electron with ACF which only conduct electron in the vertical direction. Peel strength of COF bonding area on MoTi film is lower than that of ITO film, we predicted that the surface roughness contribute to different peel strength, as shown in Fig.2a (iii), 2b(iii) and Fig.3b. Both ACF/MoTi and ACF/ITO showed a similar connection resistance, however connection resistance of ACF/bare Cu is much higher than that of ACF/ITO or ACF/MoTi due to forming of copper oxide (Fig.5). So, the MoTi/Cu/MoTi 3-layer S/D electrode can prevent Cu oxidization and maintain good connection resistance.

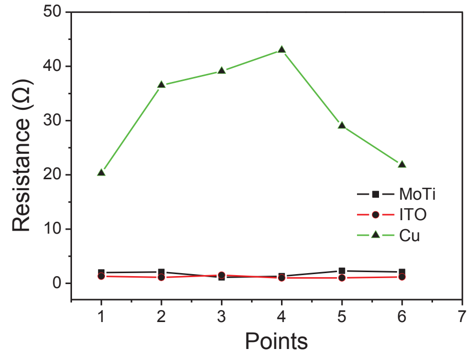

Fig.5 Resistance between COF and different metal film.

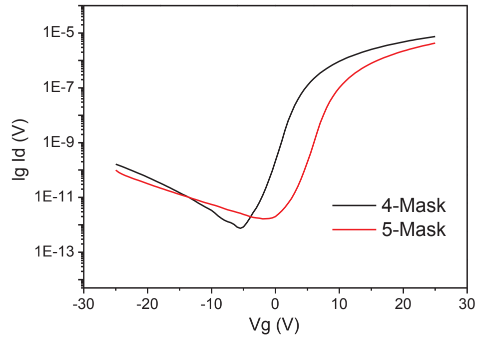

Fig.6 Transfer characteristics of miniled backlight TFTs with MoTi/Cu/MoTi and Cu as Source/Drain.

Table 1. Electrical parameters of TFTs

Sample	uFE ($cm^2V^{-1}s^{-1}$)	SS	Vth (V)	Ion/Ioff
4 mask	0.39	1.29	2.06	2238832
5 mask	0.42	1.38	2.50	2112353

For testing the effect of 3-layer metal electron on TFT electrical property, we test the I_d-V_g curve of 4-mask and 5-mask sample. Fig.6 shows the typical transfer characteristics (lg I_d-V_g at V_d = 15 V, and V_g = -25V – 25 V, where I_d is the drain current, V_g is the gate voltage, and V_d is the drain voltage) of TFTs with a ITO and a MoTi/Cu/MoTi electrodes. Moreover, their electrical performance is summarized in Table 1. It is clear that the field effect mobility, ss, V_{th}

and I_{on}/I_{off} of 4-mask sample is similar with 5-mask sample. The result indicate that the MoTi/Cu/MoTi layer as metal electrode can keep good electrical properties.

4 CONCLUSIONS

In summary, a simple and low cost strategy for fabrication mini-LED backlight with 4-mask process have been proposed, which used MoTi/Cu/MoTi as source/drain electrode and top MoTi layer of LED bonding zone was etched with dry etch. We inspected the device high temperature oxidation resistance, electrical performance of TFTs and bond strength of LED and COF. Compare to 5-mask device, the 4-mask devices shows similar properties, such as contact resistance of COF bonding zone, electrical performance of TFT and shear bond strength of LED SMT and COF.

REFERENCES

[1] T. Z. Wu , C. W. Sher, Y. Lin, C. Lee 2, S. H. Liang, Y. J. Lu, S. H. Chen, W. J. Guo, H. C. Kuo, and Z. Chen, “Mini-LED and Micro-LED: Promising Candidates for the Next Generation Display Technology”, Appl. Sci., Vol.8, 1557-1574(2018).

[2] Tang B, Miao J, Liu Y, et al., “Enhanced Light Extraction of Flip-Chip Mini-LEDs with Prism-Structured Sidewall.” Nanomaterials., Vol.9, 319(2019).

[3] West E G., “Fluxing action in welding aluminum.” Transactions of the Institute of Welding, Vol.4, 55 (1941).

[4] T. Laurila, V. Vuorinen, J.K. Kivilahti, “Interfacial reactions between lead-free solders and common base materials.” Materials Science and Engineering R: Reports. Vol. 49, 1-60(2005).