Study on Flexible and Transparent mini-LED direct display for High-end Public Information Display

Xinchen You*,1, Xiaobo Hu, Qinzun Lin, Zhixiang Fan, Rui Zhao, Jinming Li, Chaode Mo

* youxinchen1@tcl.com

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

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Abstract: *To produce a flexible transparent mini-LED screen consists of IGZO TFT fabrication on Clear Polyimide(CPI) substrates, mini-LED chips SMT on the drive circuit, and LLO to strip CPI from glass substrates. With high brightness, transparency and low energy consumption, the display panel can be an ideal solution for high-end Public Information Display(PID).*

1. Introduction

Mini-LED, known as sub-millimeter light emitting diode, the size of which is generally 80~200 um. Being a new generation technology, the small pitch mini-LED display not only has the merit of high efficiency, brightness and reliability, as well as low response time, but also its low cost and energy consumption trait attracts emerging attention recently.

In recent decade, development and application of transparent display prospers referring to PID territory. Comparing to conventional scheme of COB(COF(Chip on Film) on PCB(Printed Circuit Board)), glass based mini-LED display, with higher transmittance and smaller pixel pitch, is undoubtedly an excellent ideal solution for transparent PID scenes. Flexible transparent mini-LED, not only possessing the merits of glass based mini-LED display, but also bendable and shapeable is suitably applied to some arcuate as well as circular PID scenes.

In this paper, the whole process flow, material development as well as key process technology of manufacturing a flexible transparent mini-LED display panel are elaborated and introduced in section 2, while an exhibit Demo and its application scenarios are expounded in section3.

2. Description of flexible screen Manufacture

2.1 Design Scheme

Schematic structure of the exhibit Demo is shown in Figure.1, where two pieces 25-inch flexible transparent mini-LED display panel are spliced, below and above the panel surface a piece of polyethylene terephthalate(PET) film are pasted respectively. Moreover, PET film is a kind of colorless, transparent material with excellent mechanical properties, high hardness and toughness as well as puncture and friction resistance, which can prevent mini-LED screen from being scratched.

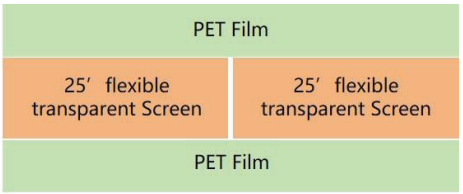

Figure.1 Schematic structure of the exhibit Demo

As shown in Figure 2, the whole process flow can be illustrated as follows: firstly, CPI substrate which liquid PI material is usually coated to the glass then baked in vacuum oven is prepared. Next, TFT backplane will be fabricated

onto the aforementioned CPI substrate by a series process cycle of thin film deposition, photolithography and etching. Then, approximately 116,640 LED chips will be transferred onto the TFT backplane by Surface Mount Technology(SMT), and package glue will seal afterwards so as to protect the LED chips from being scratched. Finally, with the module processes, including COF and PCB bonding, Laser Lift Off(LLO) to strip the flexible screen from the below glass substrate, as well as splicing and protection film pasting, the final exhibit Demo is fabricated.

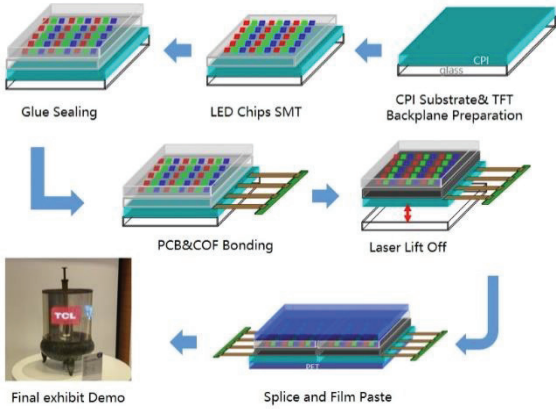

Figure.2 Whole process flow of the exhibit Demo

2.2 Material Development

Among the whole process, material development consists of CPI substrates preparation, appropriate sealing glue and PET film selection being especially critical. As for CPI substrates preparation, a liquid CPI material with yellow index below 3.0 and transmittance greater than 90% was coated as a 50-micron-thick wet film onto a 0.5-millimeter-thick glass surface. Then, after a 20-minutes 80℃ pre-bake and 30-minutes 400℃ post-bake, a 10-micron-thick dry CPI film was left on glass, or rather a flexible CPI substrate with high transmittance on spec was prepared.

Generally, the encapsulant plays a role of protecting LED chips and never catch too much attention, nevertheless in this research traits of high transmittance and bendability inevitably become the key evaluation criteria. In the Demo, a 250-micron-thick encapsulant with approximate 92% transmittance while its curvature radius is within 50-millimeter is selected. Referring to the PET film which has been introduced above and will not be repeated here.

2.3 Flexible and Transparent Backplane Development

As mentioned and introduced before the exhibit Demo is spliced by two single screens, which are fabricated by 25-inch nine masks process. Moreover, the chip size of single screen is 405mm*486mm, the resolution, aperture ratio and LED chip pitch of which are 180RGB*216, 77%, and 2.0mm respectively.

A normal 3TFT-1C driver circuit structure is selected, in which Indium Gallium Zinc oxides (IGZO) Top Gate(TG) TFTs driver is used allowing for both the mass production and PID application scenes. Relatively high on-state current and low off-state current of IGZO TFTs driver can not only provide higher contrast ratio, but also makes high luminosity of LED chips possible. High brightness is non-negligible in PID scenarios which are generally applied in outdoors and demanding relatively long viewing distance, determining the final display effect.

The aforementioned TG IGZO TFTs device structure is schematically shown in Figure.3. Different from the conventional TG structure, there is an additional barrier layer between the CPI substrate and Light Shield(LS) layer. Generally, a certain thickness of SiN_x plus SiO_x complex films are deposited on the below CPI substrate as the barrier layer, so as to protect the above backplane from performance deterioration by the volatile of CPI material during the following high temperature processes. Besides, the barrier

layer composed by SiN_x and SiO_x complex films, playing an important role in balance the multi-stress to alleviate the substrate warping, is indispensable in the flexible screen fabrication. Warping issue may directly lead substrates being scratched, thereby result in backplane failure and yield loss. Last but not the least, above the TG structure TFTs, a 10-micron-thick transparent layer of perfluoroalkoxy (PFA) or photo spacer (PS) is coated on the backplane to protect the below backplane from being scratched, which will be elaborated in the next section.

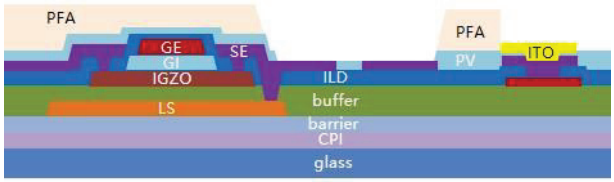

Figure.3 Schematic structure of TG IGZO TFTs device

2.4 Transparent Display Module Process Development

During the module process, firstly LED chips will be transferred onto the TFT backplane by SMT process which consists of solder paste printing, mounting, chips curing, reflow soldering, inspection, repairing, package glue sealing and etc. steps. However, the TFT devices would short and fail, for the crack of metal films in the plane by the downwards pressure of the steel mesh when prints the solder paste. Therefore, the PFA or PS material, introduced in the previous section, should be implied as an anti-scratch layer between the backplane and the mounting chips. To balance process capability of the photolithography equipment, transmittance of the backplane, and anti-scratch effect, a 10-micron thickness of the PFA layer is selected.

LED chips selection almost determines peak brightness and produce costs of the screen, in the meantime, different LED chips have different height which would influence the total thickness of the screen thereby having impact on the curvature radius and transmittance of the screen. Therefore, 0509(5.0 mil *9.0mil)-size LED chips are selected, taking all issues in account. Following that, an approximately 200~300-micron-thick encapsulant is sealing onto the mounted LED chips by inkjet printing.

Then, COF and PCB will be bonded onto the sealed backplane, which won't be introduced in detail here, for Outer Lead Bonding(OLB) is a common and mature process. Afterwards it comes another key process, Laser-Lift off, which can be a symbol to distinguish the flexible screen from the normal Flat Panel Display(FPD). Utilizing the laser energy emitted by 308 nm wavelength laser, the interface between glass and CPI absorbs laser energy hence the molecular bond of CPI surface breaks when the laser casts and scans from the glass side, so that the screen on CPI substrate is stripped from the below glass. In respect of the LLO process, there are two points should be paid more attention to. For one thing, the glass side, namely the backside of screen should be thoroughly cleaned before LLO, especially the residue glue remained by encapsulant sealing process, which may absorb part of laser energy and results in incomplete separation when LLO. For another, an optimal laser Energy Density(ED) need be attempted and selected, for the CPI substrate is merely 10-micron thick thus the process margin of LLO is inevitably narrow. If the laser ED was chosen relatively overlarge, the interface would have been carbonized, and accordingly the TFT driver circuit on PI film would have been damaged and failed.

Finally, two pieces of the aforementioned stripped flexible screens are placed and spliced manually on the stage with vacuum absorption, meanwhile protective PET film are pasted onto the both beneath and above side of the spliced

screen. Consequently, the finished flexible transparent mini-LED screen is manufactured.

3 Results& Conclusions

A 41-inches flexible transparent mini-LED display Demo is first released globally, spliced by two independent 25-inches screen, with a transmittance over 60%, curvature radius below 100-mm as well as luminosity over 1000-nit, besides other specs can be found in Table.1. The final product form of the exhibit Demo is made as a circular showcase, shown as Figure.4, which can be applied to display scenarios of museum and mall so as to leave a more intuitive impression as well as experience on visitors and customers.

Table.1 specific specifications of the exhibit Demo

Items	Spec.
Size	41 inches
Pitch	2.0 mm
Transmittance	>60%
Curvature Radius	<100mm
Brightness	>1000nit
TFT Device	TG IGZO TFT
Total thickness	0.3mm
Splice amounts	1*2

Figure.4 Final product picture of the exhibit Demo