High Performance Oxide TFT Technology for Med.-Large Size OLED Displays

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ABSTRACT

We have developed highly reliable oxide TFT technology for the OLED displays. Even for the flexible displays or the gate driver integrated high resolution (~350 ppi) OLED displays, 10-years-lifetime is achieved. By combining OLED printing technology, we realize high productivity in middle-large size OLED display manufacturing.

1 INTRODUCTION

The study of organic light emitting diode (OLED) accelerated after the first report of stacked semiconductor device in 1987 [1]. For the application, an active matrix (AM)-OLED display has been widely developed because of its superior front of screen (FOS) quality represented by high contrast ratio and wide color gamut [2].

The AM-OLED display failed to rise for growth for more than 10 years from the first product in 2003, however finally started expanding its market share. A long time was necessary for the improvement of immature manufacturing processes and the evolution of light emissive materials. The AM-OLED display finally came to be used as an information display, however, the panel cost is still considerably higher than that of liquid crystal display (LCD) because of its complicated manufacturing method and the immaturity of the production scale.

We propose highly productive manufacturing method for AM-OLED display. To achieve high productivity, the adoption of large size mother glass substrate and the application of simple manufacturing process are effective. Our highly reliable oxide TFT technology for the active matrix device and RGB printing technology for OLED device would contribute to the innovation of OLED display manufacturing.

2 TFT REQUREMENT FOR OLED DRIVING

Because the OLED is a current drive device, the requirement to TFT for driving an AM-OLED display is quite different from that of LCD. According to the continuous current flow for the light emission of OLED device, especially high reliability against the bias temperature stress (BTS) is required for the pixel circuit. As the lifetime before reaching the threshold voltage shift limit, more than 5-digits longer lifetime in BTS test is necessary for OLED display than that for LCD [3]. In addition, further high reliability is necessary for gate driver integration, enlargement of the display, realization of the flexibility, and so on.

The most of current OLED displays employ low temperature poly-silicon (LTPS) TFT technology [2]. The high stability of LTPS TFT against high current flow is suitable for the OLED driving. Especially for the small-sized display such as a smartphone, the CMOS circuits by LTPS technology are effective in narrowing the frame of the display. However, it is difficult to use the LTPS TFT for the larger or the lower cost displays. The oxide TFT is an ideal backplane for the med.-large size OLED displays. Its low process temperature is also suitable for the flexible display fabrication. Its stability was ever a serious issue, however we have developed highly stable oxide TFT with alumina (AlOx) passivation [3], and have successfully demonstrated several kinds of prototypes (Fig.1).

3 OXIDE TFT TECHNOLOGIES FOR HIGHLY RELIABILE OLED DISPLAYS

We have reported 1) “gate driver integration” technology by high mobility material [4], 2) “upsizing and high frame-rate” technology by top-gate structured TFT [5, 6], and “flexible, and high-resolution” technology for printed OLED [6, 7, 8, 9, 10].

Fig. 2 shows the candidate of oxide TFT structures and those characteristics. An alumina film is applied as a passivation to secure the stability after OLED materials and others were formed on the TFT. As differentiation with the LTPS TFT which is advantageous for small size displays, we have proposed to use self-aligned top-gate oxide TFT with high protective AlO passivation for medium-large size displays [5, 6, 8, 9, 10]. For the cost-competitiveness, we decided that we could apply the mature production facilities which handle larger substrate than Generation 8.5 (2200×2500 mm), and applied the self-aligned TFT structure for realizing uniform TFT characteristics on the whole area of the large substrate.

3.1 Gate Driver Integration

The high mobility of the oxide semiconductor downsizes the transistor constituting the gate driver, and is effective to reduce the peripheral circuit region of the display. We have confirmed approximately 3 times higher mobility (30.9 cm^2/Vs) than that of standard a-IGZO by utilizing a-ITZO [4]. The composition with higher mobility is possible, however it tends to have the tradeoff relationship with the width of the process window.

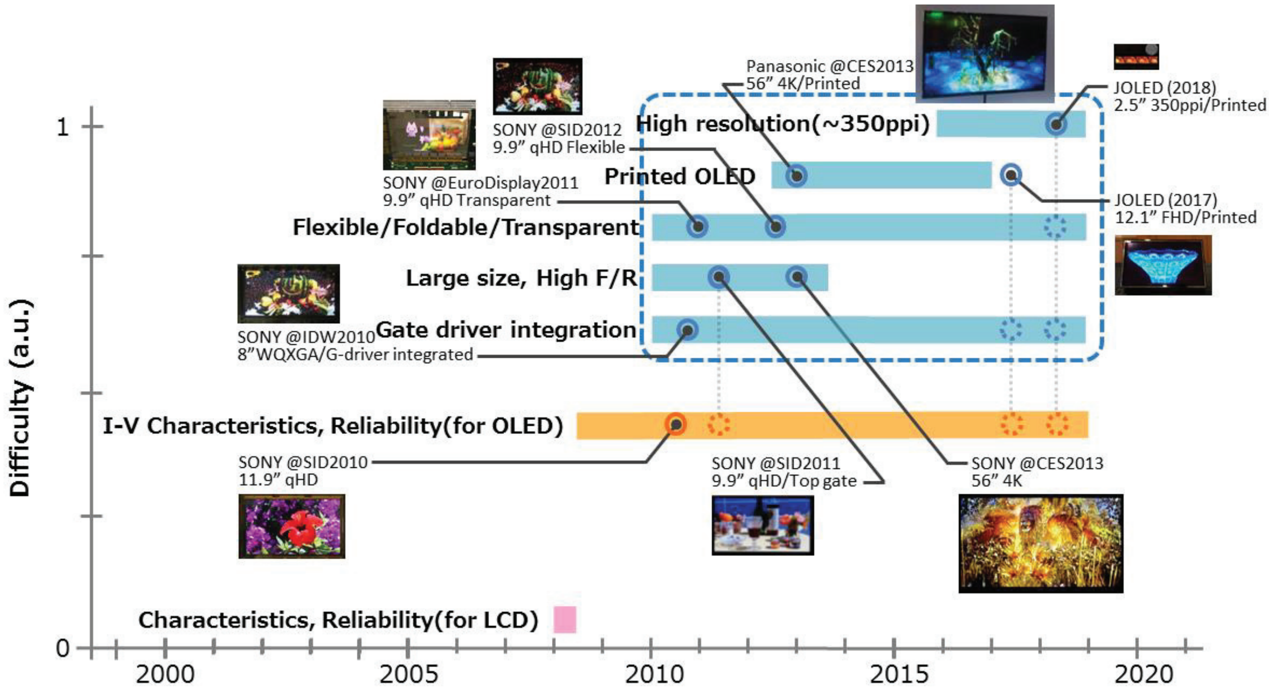
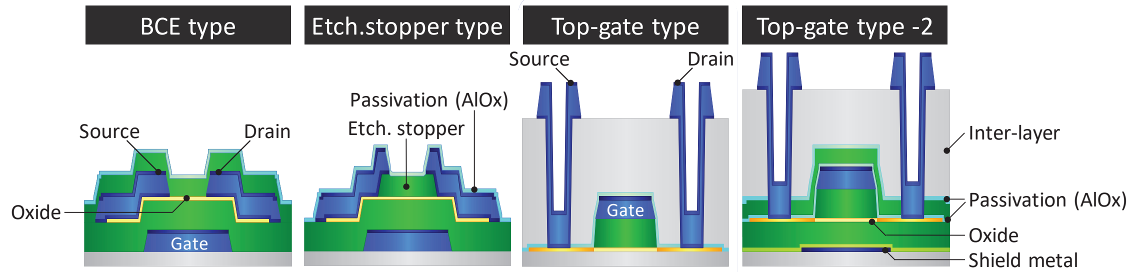


Fig. 1 The history of oxide TFT development for OLED displays.



	BCE type	Etch.stopper type	Top-gate type	Top-gate type -2
Mask number	≥ 4	≥ 5	≥ 4	≥ 5
TFT reliability L≥6μm	Med.	Med.	High	High
TFT reliability L<6μm	Low	(Impossible)	Med.	High
TFT parasitic capacitance	Med.	Large	Small	Small
Cross line capacitance	Large	Large	Small	Small

Fig. 2 Cross-sectional structures of oxide TFTs and those characteristics.

3.2 Upsizing and High Frame-rate

To achieve the uniform emission from each pixel, a pixel compensation circuit is employed. Even in the case of simplest 2-transistors circuit [3], there are many capacitors in a pixel. When the parasitic capacitance of TFT: Cp and the inter-layer capacitance: Cin become large, the signal shape become dull due to the RC delay, and high resolution or high frame rate driving becomes difficult.

To reduce the Cin, we propose to use the thick organic material as an inter-layer. For a capacitor of the conventional silicon compound system, the inter-layer capacitance between gate line and signal line becomes approximately 1/5 (Fig. 3).

To reduce the Cs, we propose to apply the self-alignment process to the patterning of source/drain of the TFT. For a transistor fabricated by the conventional photo-lithography process, the parasitic capacitance between gate and source nodes of the TFT becomes approximately 1/3 (Fig. 3).

The ability of the compensation operation is called a bootstrap gain (Gb), and is expressed by the following equation [11].

$$Gb = Cs / (Cs + Cp + Cothers) \quad (1)$$

Here, Cs is the capacitance of the storage capacitor, Cp is the capacitor between gate and source nodes of the write scan transistor, and Cothers is the parasitic capacitor between gate node of the drive transistor and the other structurally nearby nodes. The reduction and the uniformalization of the parasitic capacitances (Cp and Cothers) according to the self-alignment process are effective to realize accurate compensation driving.

By applying self-aligned top-gate TFT structure, both of the small (Cin and Cp) for suppressing RC delay and the small and uniform (Cp and Cothers) for improving the compensation ability can be realized.

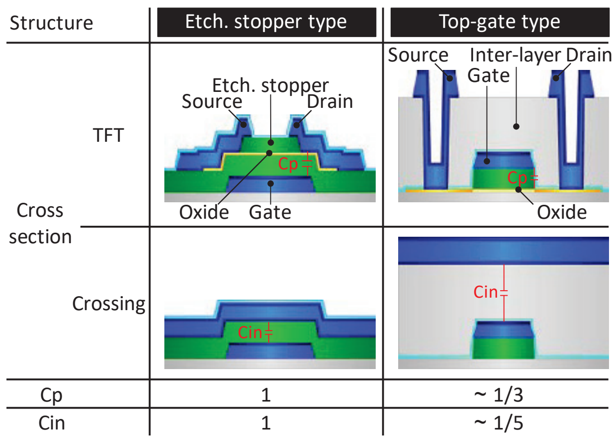


Fig. 3 Cross-sectional views and parasitic capacitances.

3.3 Flexible, High-resolution, and Printed OLED

We have confirmed the high reliability of the OLED devices, which were fabricated between two pieces of glass substrate [3, 4, 5]. Even in the case of printed OLED which solution materials were applied to, reliability high enough is secured by the high passivating properties of the alumina film [6].

However, higher reliability is required in the flexible or the high resolution displays. Particularly, TFT characteristics become easy to degrade in the short channel TFT less than L=4 μm in a high resolution display. Hydrogen in the adjacent film to the semiconductor layer is occasionally used to stabilize TFT characteristics, however excess hydrogen, water, oxygen or other movable ions move to the semiconductor layer by the stress of heat or the electric field and sometimes degrade the TFT characteristics [10]. As these measures, the double-layered alumina passivation and the insertion of shield metal were proposed (Fig. 4). These were technical options up to demand performance, however the reliability improvement in the demonstration panel were confirmed.

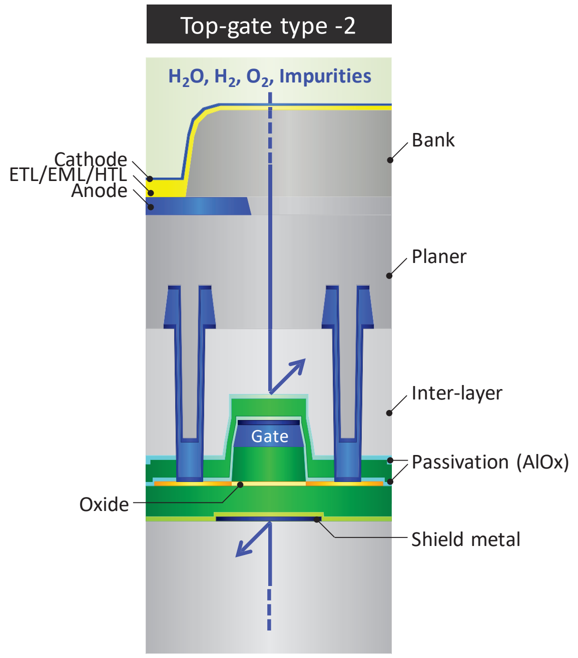


Fig. 4 High reliability structure for short channel TFT.

Fig. 5 shows an image of the high-resolution printed OLED display, and Table 1 summarizes its specifications. The short channel TFT realized high pixel resolution and the gate driver integration. Even though the soluble RGB emitters were printed on the oxide TFT array, high reliability was realized in the acceleration stress test. Fig. 6 shows the threshold voltage shift (ΔVth) during high-temperature stress (HTS) test at T=70°C in dry air, and high-temperature-humidity stress (HTHS) test at T=60°C and 90%RH. The ΔVth was negligibly small at less than 0.1 V after 4,000 h in both the HTS and HTHS tests. Enough reliability was confirmed for the high-resolution printed OLED display.

Fig. 5 Oxide TFT driven 352ppi printed OLED display.

Table 1. Specifications of the prototype.

Panel size	2.8-inch diagonal
Resolution	152 x 960
Brightness	Peak : > 350 cd/m^2
Contrast	> 1,000,000 : 1 (Dark)
Gate driver	Integrated

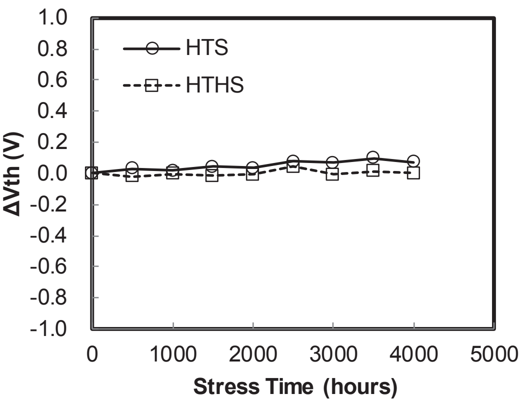


Fig. 6 ΔVth during HTS test and HTHS test.
(HTS: T=70°C in dry air, HTHS: T=60°C at 90%RH.)

4 DISCUSSION

According to these technologies, we could achieve quite attractive OLED displays with stable driving. The manufacturing equipment for our oxide TFT is compatible with that for amorphous silicon TFT, and is possible to be adopted to the FAB using large substrate over Generation 8.5. Moreover, we employ RGB printing technology for the OLED patterning. This technology is performed with a simple process flow and don't use the fine-metal mask, which has limitations in the mask size and the panel size. Therefore, the OLED manufacturing with a large substrate is applicable. We expect both of the oxide TFT and printed OLED technologies, which have characteristics into simple device structure and high productivity, contribute to the cost down and the market expansion of the OLED display.

5 CONCLUSIONS

The high reliability of the OLED display is realized with high productivity by the AlO-passivated self-aligned top-gate oxide TFT technology. Especially for the short channeled TFT for the high resolution display or the TFT for the flexible display, we have prepared technical options to maintain the high reliability of OLED display.

Because both the oxide TFT and the printed OLED are manufactured by the simple process flow and large substrate over Generation 8.5, we can realize highly reliable and highly productive manufacturing for the med.-large size OLED displays.

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