Development of High Mobility Top Gate IGZO-TFT for Automotive OLED Display.

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ABSTRACT

High performance IGZO-TFT with top gate structure was developed for automotive OLED display backplane. By optimizing the process conditions, we achieved the mobility of 32 cm^2/Vs with enhanced threshold voltage. The PBT/NBT/NBIT reliability are good enough to use in OLED application. The prototype 12.3" flexible automotive OLED display was successfully demonstrated.

1 INTRODUCTION

In 2004, amorphous oxide semiconductors (AOSs) was reported as a promising active layer material for the next generation thin film transistor (TFT) [1]. Since then, many achievements have been reported by laboratories and companies. Several companies have been successfully mass-produced display device with AOS, notably In–Ga–Zn–O (IGZO)-TFT. SHARP Corp. started mass production of the IGZO-LCDs since 2012 and it was the first time in the world [2]. From then, we introduced many products like Smartphone, PC, and TV using IGZO-TFT panel.

IGZO-TFT has some advantage over conventional TFTs. The mobility is 10 times higher compare to a-Si TFT. This is an advantage in drive speed and high resolution. Another is the low leak-current at off state, which is 1/1000 compare to a-Si, that is necessary for low frequency and low power consumption devices. IGZO-TFT shows good threshold voltage (V_{th}) uniformity in large substrate for G8 factory. It is very important for large size display mass production. However, there are some issues of IGZO-TFT such as the reliability. For the current-driven displays, characteristics degradation directly affects brightness. During stress, especially under illumination, defects can be easily generated in the IGZO subgap [3]. Recently, LG display starts mass production of OLED-TV using IGZO-TFT and reported excellent V_{th} uniformity and reliability [4].

High mobility is a key technology to realize the display devices full potential [5]. It can drive at low voltage, which can reduce the power consumption. In addition to that, reduction of TFT size is possible for high resolution and narrow bezel display. For small to medium size display backplane, low temperature poly silicon (LTPS) is the most popular material with high mobility TFTs, which is not suitable for large area and low power consumption display device. Considering this situation, we need to improve the mobility of IGZO TFT equal to the LTPS TFT.

We established mass production of back channel etch type IGZO-TFT in 2015. We call this technical generation "IGZO3" which means the 3rd generation of IGZO. Since IGZO3, we have improved the mobility by 1.5 times higher and evolve the generation, like IGZO3, IGZO4, IGZO5, and now IGZO6-7 is being developed [6].

We are aiming to adopt the IGZO technology in automotive OLED display to take advantage of its excellent properties. Table.1 summarized a comparison between internal, internal plus external, and IGZO-TFT with external compensation. External compensation can bring the most accurate adjustment of brightness for image sticking free. IGZO-TFT is suitable for external compensation because of its excellent off characteristic. In addition, by adopting the external compensation, it is possible to reduce the circuit that reads the current value in the pixel, so the number of TFTs can be reduced. Therefore, we will have the design and process flexibility, as well as high yield.

In this paper, top gate IGZO-TFT with high mobility are successfully manufactured for automotive OLED display panel. IGZO-TFT shows high mobility with enhanced threshold voltage. It has also shown that the reliability under PBT/NBT/NBIT is small enough to widely adopt in mass-production. Finally, we fabricated the prototype 12.3" ultrawide OLED display with high brightness uniformity.

Table 1. Comparison between internal, internal & external and IGZO-TFT & external compensation.

			Internal	Internal + External (Camera)	IGZO External (Sensing)
Compensation Timing			Real time	Real time + In assy. line	Real time + Internal during operation
Purpose			For initial compensation (Limited aging compensation)		For aging compensation
Image Sticking Items	TFT (Vth)	Initial	✓	✓	✓
		Aging	✓	✓	✓
	TFT (Mobility)	Initial		✓	✓
		Aging			✓
	OLED (I-V)	Initial		✓	✓
		Aging			✓

2 EXPERIMENT

2.1 TFT and hall sample structure

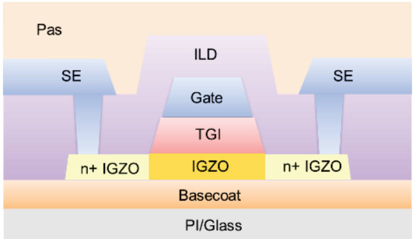

Fig. 1 Schematic cross-sectional view of the fabricated top gate IGZO-TFT.

Top gate IGZO TFTs were fabricated on a PI/glass substrate, as shown in Fig. 1. A dielectric base coat layer was deposited using plasma-enhanced chemical vapor deposition (PECVD). The IGZO film was sputtered as an active layer and patterned with photolithography and wet etched. Top gate insulator (TGI) and top gate metal (TGE) were deposited on the IGZO channel by PECVD and sputter, respectively. The TFT properties strongly affected by the top gate metal work-function, thus optimization of the gate material is also an important factor. Herein, 300-nm-thick titanium/aluminum/titanium film was used as the gate electrode. After patterning and dry etch both the TGI and TGE, dielectric interlayer (ILD) was deposited. For top gate IGZO TFT, a conductive region (n+ IGZO) is needed to contact active channel and electrode. After opening the contact holes by photolithography and dry etching, stacked titanium/aluminum/titanium was deposited as the Source/Drain electrodes (SE). Considering the TFT's characteristics and reliability, the passivation layer was chosen carefully. During the process, several annealing steps also applied to activate the TFTs. The channel length (L) and width (W) of the TFTs were 7.5 and 10 μm, respectively. Note here, all the process parameters are selected to satisfy the mass production. Observed by scanning electron microscope (SEM), we found that those TFTs were fabricated without any serious damage such as delamination of the barrier layer, over etching of the channel region, or poor coverage of the dielectric interlayer.

For Hall mobility measurements, 100-nm-thick IGZO film was deposited on the glass substrate.

2.2 Process optimization

To enhance the mobility we have engineered the IGZO process. Figure 2 shows the hall mobility of different IGZO process as a function of the carrier concentration. Every times the IGZO process evolve, the hall mobility increase. From IGZO3 to IGZO6-7 the hall mobility becomes 10 cm^2/Vs to 50 cm^2/Vs. However, the carrier concentration also rise in orders, which is similar to the previous reports of high mobility AOS [7]. For n-type semiconductor the threshold voltage is related to the carrier concentration.

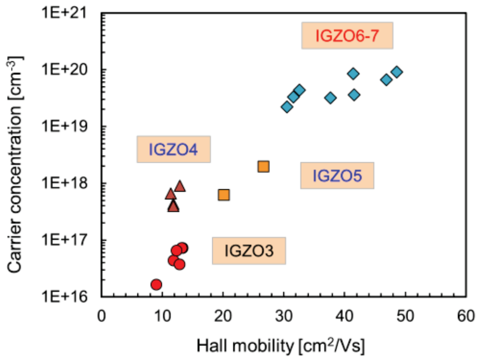

Fig. 2 Hall mobility and Career concentration of various IGZO.

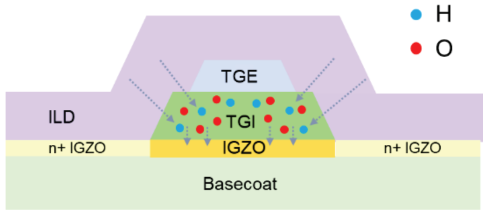

Fig. 3 Schematic diagram of Hydrogen and Oxygen balance in the IGZO channel

We found that, if the carrier concentration is over 20th order obtaining an enhancement mode TFT becomes very difficult. From that point of view, we have controlled the carrier concentration of the new high mobility IGZO process (IGZO6-7) below 10^{20} cm^{-3} and realized the hall mobility of 50 cm^2/Vs.

Several process optimization is needed to fabricate good quality top gate IGZO TFTs for mass production. Obtaining the enhancement mode TFTs with good uniformity is a challenge. First we have optimized the process to control the threshold voltage (V_{th}). The arrangement of the process was based on the Microwave photoconductivity decay (μ–PCD) method [8]. From the μ–PCD peak reflectivity, the defect state of the IGZO film can be determined after every processing step.

In order to suppress the depletion mode, oxygen vacancy of the IGZO channel need to be reduced. Threshold voltage can be positively shifted by adding oxygen in the IGZO film during the fabrication process, however, the on current and mobility would decreases significantly. Moreover, excess oxygen create weakly bonded –OH and V_{th} shift under the stress [3]. Previously, reported that the reliability can be improved by increasing hydrogen in the TGI [4]. However, diffused H in the IGZO channel also act as a shallow donor and increase the carrier density. Therefore, we have introduced a process to supply balanced oxygen and hydrogen in the TGI and IGZO channel as shown in the Fig 3. By introducing oxygen to some extend and balancing hydrogen the V_{th} becomes around 0 V, and high mobility as well as high reliability were obtained at the same time.

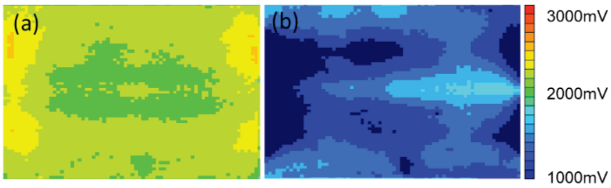

Fig. 4 μ–PCD mapping for the (a) conventional and (b) optimized process.

Figure 4 (a) and (b) shows the μ–PCD mapping of the conventional and optimized process, respectively. The conventional process shows an average peak reflectivity of 1166 mv with a uniformity of 55%, whereas the optimized process shows an average peak reflectivity of 2334 mv with a uniformity of 16%.

When the same conditions were applied to a different IGZO process, especially to the high mobility IGZO6-7, the TFT characteristics trend to be in depletion mode. After changing various IGZO6-7 process parameters we have achieved enhancement mode TFTs with great uniformity.

3 RESULTS

3.1 TFT Performance

The transfer characteristic of the TFTs were measured by Agilent B1500A semiconductor analyzer at room temperature in dark. The field effect mobility (μ_{EF}) was calculated by the following equation in the linier region using a small V_d of 0.1 V [3].

$$\mu_{EF} = g_m \frac{L}{W\, C_{OX} V_D}$$

Where g_m is the transconductance and its value can be obtained by $g_m = \mathrm{d}\, I_d / V_g$.

The V_{th} of the IGZO TFTs were maintained in enhancement mode and almost similar to the other TFTs, as shown in Fig 5. Table 2 listed the value of the mobility, threshold voltage and hysteresis of the TFTs with different IGZO process. All the TFTs shows good performance with very small hysteresis and sub threshold swing. Despite very low off state, the on current gradually increased with the IGZO process evolved. As a result, the mobility for IGZO3, IGZO4, IGZO5, and IGZO6-7 become 7,12, 18, and 32 cm^2/Vs, correspondingly.

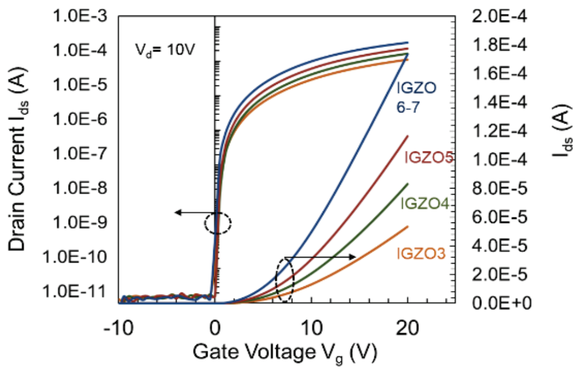

Fig. 5 Transfer characteristics of IGZO TFTs.

Table 2. Electrical characteristics of the TFTs

	IGZO3	IGZO4	IGZO5	IGZO6-7
μ_{EF} [cm^2/Vs]	7	12	18	32
V_{th} [V] σ	0.5 (0.13)	0.3 (0.12)	0.5 (0.10)	0.4 (0.15)
Hys. [V]	0.05	0.04	0.08	0.08

In general, the oxygen vacancy supply the electron and enhance the mobility. However, the IGZO6-7 exhibited positive V_{th} with high on current. Mention here, it was confirmed that the channel length of the TFTs with different IGZO process were mostly equal. Therefore, the oxygen deficiency was successfully compensated by balancing the oxygen and hydrogen supply and the origin of the high mobility is IGZO6-7 process.

3.2 TFT's Bias Stress Reliability

Figure 6 (a) summarized the V_{th} shift under positive and negative bias temperature stress (PBT and NBT) for the TFTs with different IGZO process. A gate voltage stress of +30 V and -30 V was applied for 3,600s at a stress temperature of 60°C. Under PBT stress the positive V_{th} shift increase from 0.2 V to 0.35 V for the IGZO6-7 device. Under NBT stress, the negative V_{th} shift of the IGZO6-7 is -0.35 V, which is reasonable for high mobility TFTs. The NBIT test shown in the Fig. 6 (b) was conducted as similar condition of the NBT with a white light of 2,500 lux. The negative V_{th} shift under NBIT stress trend to gradual increase with the IGZO TFT's mobility enhancement. Compared with the LCDs, the TFT in the OLED display is less effected by the light, thus the NBIT degradation value of the high mobility TFT would not impact the mass-production. Nevertheless, the PBT and NBT shift for IGZO6-7 is +0.3 and -0.3 V, as well as the NBIT shift is under 1 V, which is small enough to use in OLED display devices.

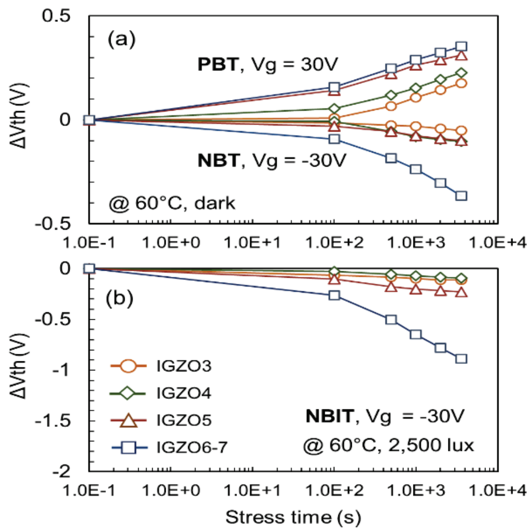

Fig. 6 Vth shift of various IGZO process under (a) PBT and NBT (b) NBIT stress.

3.3 Ultrawide flexible OLED display

Fig. 7 Fabricated prototype flexible OLED display

Table 3. Specifications of the display

OLED	Top emission
Size	12.3” Ultrawide
Resolution	1920 x 720 x RGB (167ppi)
Brightness	600 cd/m^2
Substrate	Polyimide

We have demonstrated a 12.3” ultrawide flexible OLED display, using top emission OLED structure and high mobility top gate IGZO-TFT backplane as shown in the Fig.7. The display having narrow bezel and can be bended at a curvature radius of R=5 mm. The specifications of the display are listed in Table 3.

The prototype display showed an excellent brightness uniformity. The device can be operated under high temperature of 85°C to low temperature of -40°C. The display also tested under stress with a temperature and humidity of 60°C and 90%, respectively for longtime. The device and backplane was remain working in good condition even after 1,000 hours.

4 CONCLUSIONS

In summary, we have developed high mobility top gate IGZO-TFT and successfully adopted in a flexible OLED display panel. The mobility of TFTs are reach to 32 cm^2/Vs and the threshold voltage of 0.5 V with excellent uniformity. The estimated ΔV_{th} of the TFTs under the stress are small enough to use in the OLED panel. Therefore, TFTs using high mobility IGZO-TFT is suitable for automotive OLED display panel.

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