High-Mobility Metal-Oxide TFT Development for IT AMOLED Applications

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Abstract
In this paper, we demonstrated the high mobility metal oxide TFTs with small Vth variation and good electrical reliability in Gen. 6 and Gen. 4.5 factory. Moreover, The 13.2 and 12.6 inch AMOLED displays have been successfully developed with MO-1 and MO-2 backplane technology, respectively. Furthermore, the MO-3 metal oxide TFTs were fabricated with high mobility (55 cm^2/Vs) by using atom layer deposition (ALD) technology.

Author Keywords
Metal Oxide TFT; High mobility; AMOLED

1. Introduction
Active matrix organic light emitting diode (AMOLED) has attracted a considerable attention for the next IT display applications. Because AMOLED exhibits higher contrast ratio, wider range of colors and faster response time than LCD [1]. Consideration of backplane technology for IT AMOLED applications, low temperature poly silicon (LTPS) and LTPO backplane technology are limited in their application in large-generation AMOLED factory due to high production costs and large-area electrical uniformity issues. Although, metal oxide thin-film transistor (TFT) is a potential backplane technology for large-generation factory mass production for next IT AMOLED display owing to its low production cost and good electrical uniformity in large area. In order to achieve small gate in pixel (GIP) area for narrow border and high output current for high refresh rate in middle-size IT AMOLED display, high mobility property for metal oxide TFT is needed [2].

However, the electrical reliability issues is the main problem of high mobility metal oxide TFT such as bias temperature stress, bias illumination stress and oxygen vacancy defect control. In this study, three kind of different metal oxide TFT devices, designated as MO-1, MO-2 and MO-3, were demonstrated. The field-effect mobility of MO-1, MO-2 and MO-3 were higher than 30, 40 and 50, respectively. Consideration for mass production applications, the electrical uniformity and electrical reliability of high mobility metal oxide TFTs were improved by optimized process conditions. Furthermore, we have successfully developed 13.2 and 12.6 inch AMOLED display with MO-1 and MO-2 backplane technology, respectively.

2. Experimental Section
The high mobility metal oxide TFTs were top gate self-align with bottom gate structure shown in figure 1. We deposited MO-1 and MO-2 as channel layer by using physical vapor deposition (PVD) on Gen 6 PI flexible substrate and G4.5 rigid glass substrate. The MO-3 metal oxide TFTs were fabricated the high mobility channel layer by using ALD technology. The electrical and reliability characteristics of high mobility metal oxide TFTs were performed by using a semiconductor parameter keysight B1500A. The gate voltage range for Ids-Vgs measurements were set from -15 to 15 V. The positive bias temperature stress (PBTS) test conditions was 30 V gate bias at temperature of 60 °C for 12 hours. The carrier concentration and Hall mobility for high mobility metal oxide films were analyzed by Hall measurement.

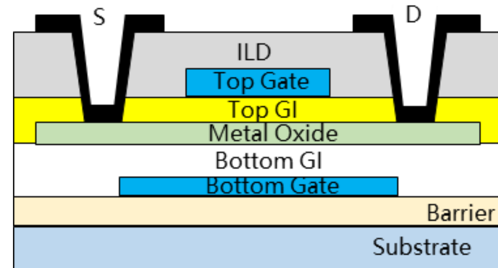

Figure 1. Cross-section structure of self-aligned metal oxide TFTs with bottom gate.

3. Results and Discussion

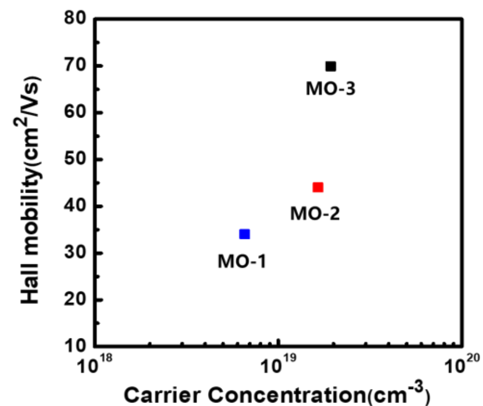

Figure 2. Carrier concentration and Hall mobility of different metal oxide films.

Table 1. Hall measurement of MO-1, MO-2 and MO-3 films

	Carrier concentration (/cm^3)	Hall mobility (cm^2/Vs)
MO-1	6.57E18	34
MO-2	1.65E19	44
MO-3	1.93E19	69.9

The Hall measurement results of MO-1, MO-2 and MO-3 were shown in figure 2 and the values of carrier concentration and Hall mobility were shown in Table 1. The carrier concentration of 6.58E18/cm^3, 1.65E19/cm^3 and 1.93E19/cm^3 were observed with

ISSN 0097-996X/25/5602-0840-$1.00 © 2025

MO-1, MO-2 and MO-3 thin films, whereas the Hall mobility of 34 cm^2/Vs, 44 cm^2/Vs and 69.9 cm^2/Vs were found with MO-1, MO-2 and MO-3 thin films. The MO-3 film exhibited higher Hall mobility close to 70 cm^2/Vs, which can be related to the lower number of defects and denser film layer by ALD process [3-4]. However, high carrier concentration of metal oxide films would lead to negative Vth performance of high mobility metal oxide TFT. Besides, we need to adjust the deposition and annealing condition to obtain the suitable electrical performance of high mobility metal oxide TFTs.

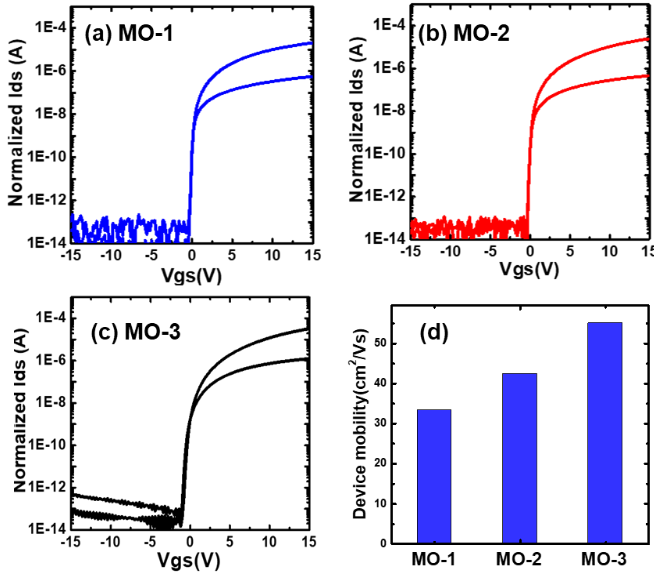

Figure 3. Transfer curves of (a) MO-1, (b) MO-2, and (c) MO-3 metal oxide TFTs. (d) The mobility value of different metal oxide TFTs.

Figure 3 (a), (b) and (c) showed the transfer curves of MO-1, MO-2 and MO-3 metal oxide TFT devices. The Vth values of MO-1, MO-2 and MO-3 metal oxide TFT were 0.19V, 0.04V and -0.15V. The mobility values of MO-1, MO-2 and MO-3 were 33, 42 and 55, respectively were shown in figure 3 (d). We can achieve high mobility reach to 55 cm^2/Vs by using ALD technology. We believe that ALD is a great potential technology for full oxide backplane application to replace LTPO backplane technology.

Moreover, the electrical uniformity is the one of important factor for mass production evaluation. Therefore, The Vth variations of MO-1 and MO-2 TFTs were be evaluated shown in Figure 4. The Vth distribution of MO-1 oxide TFTs was showed in figure 4(a), which demonstrated a small Vth variation (0.21V max-min) with 36 points on the Gen. 6 PI/glass substrate (1500*1800mm). This result indicated that MO-1 oxide backplane technology is possible to achieve good brightness uniformity for AMOLED mass production, especially in medium-size display. The Vth distribution of MO-2 oxide TFTs was showed in figure 4(b).

The Vth range of MO-2 oxide TFTs was 0.46V with 20 points on the Gen. 4.5 glass substrate (730*920mm). The Vth distribution of MO-2 oxide TFTs probably can be further improved through the distribution of oxygen vacancy in metal oxide deposition process and the uniformity of hydrogen contents in buffer and gate insulator films.

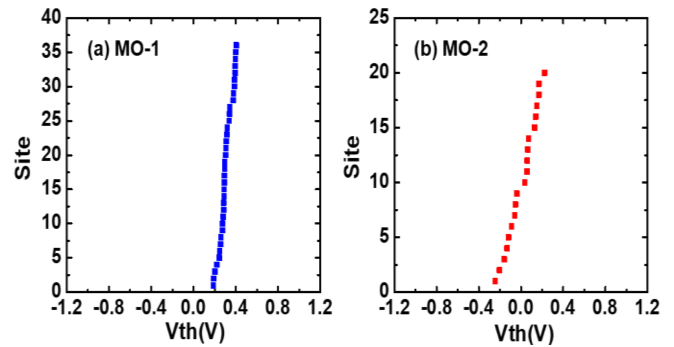

Figure 4. The Vth distribution of (a) MO-1 and (b) MO-2 metal oxide TFTs on Gen. 6 and Gen. 4.5 glass area.

Figure 5(a) and (b) showed the transfer characteristics of MO-1 and MO-2 oxide TFT devices under 30V gate bias stress at temperature of 60 °C as a function of stress time, respectively. After 12 hours stress, the positive parallel Vth shift of 0.5V and 1V were observed for MO-1 and MO-2 oxide TFT devices, respectively. Moreover, there were no significant changes in the field effect mobility and subthreshold swing (SS). The MO-1 oxide TFT exhibited a small Vth shift after long tern PBTS, which can be related to the well control of oxygen vacancy defects by optimized process condition. The electrical reliability of MO-2 oxide TFTs demonstrated a larger Vth shift than MO-1 oxide TFTs, which probably due to a larger number of deep energy defects in metal oxide channel layer with higher mobility metal oxide material [5].

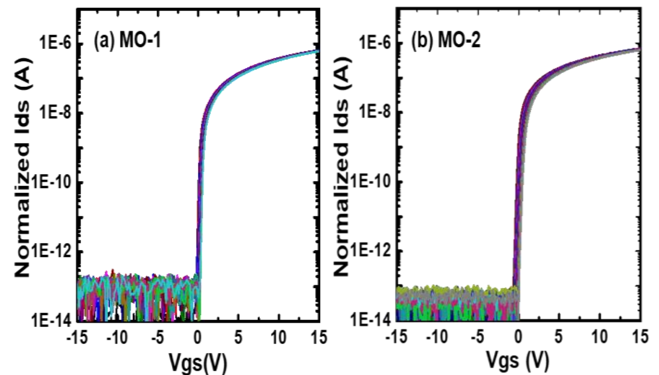

Figure 5. The transfer curves of (a) MO-1 and (b) MO-2 oxide TFT devices under 30V gate bias stress at temperature of 60 °C as a function of stress time.

In order to investigate the AMOLED middle-size panel reliability with the high mobility metal oxide backplane technology, the AC voltage with the high temperature and illumination stress was applied for the MO-1 and MO-2 oxide TFTs. We obtained the actual AC working voltage of 255 gray level through circuit simulation. The Vth shift of MO-1 and MO-2 metal oxide TFTs as a function of stress time under 255 gray level AC stress and 255 gray level AC stress at high temperature with illumination were shown in Figure 6. (a) and (b), respectively.

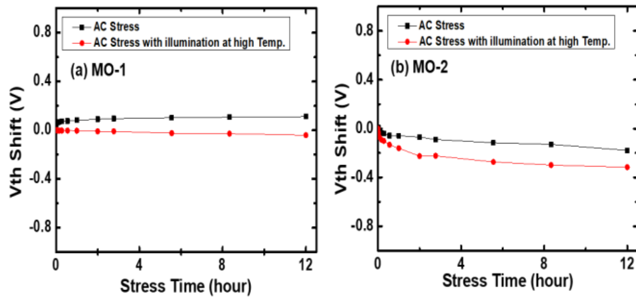

Figure 6. The Vth shift of (a) MO-1 and (b) MO-2 oxide TFT devices under 255 gray level AC stress at high temperature with illumination as a function of stress time.

In figure 6. (a), a small positive Vth shift of 0.11V was found in 255 gray level AC stress after 12hr, while a small negative Vth shift of -0.04V was observed in 255 gray level AC stress at high temperature with illumination after 12hr. The positive Vth shift of MO-1 metal oxide TFT in 255 gray level AC stress can be related to the negative charge trap at GI and/or GI interface [6]. However, the negative Vth shift of MO-1 metal oxide TFT in 255 gray level AC stress at high temperature with illumination can be explained through the extra oxygen vacancy generation during the thermal and illumination effects [7]. In figure 6. (b), the MO-2 metal oxide TFTs exhibited negative Vth shift of -0.17V and -0.31V under 255 gray level AC stress and 255 gray level AC stress at high temperature with illumination for 12hr, respectively. This two kind of different behaviors of Vth shift under 255 gray level AC stress for MO-1 and MO-2 metal oxide TFTs indicated that number of defects in metal oxide channel layer for MO-2 metal oxide TFTs were easier generated than MO-1 metal oxide TFTs under the same AC stress condition. We assumed that the electrical reliability of MO-2 metal oxide TFTs can be further improved by metal oxide deposition and annealing condition. From the 255 gray level AC stress results, we believe that the good AMOLED display performance would be obtained by using MO-1 and MO-2 metal oxide TFTs backplane technology such as lifetime and image sticking.

Figure 7. 13.2 inch full oxide AMOLED display with high mobility MO-1 metal oxide TFT backplane technology.

Table 2. The specification of 13.2 inch panel with MO-1 metal oxide TFT backplane technology.

	Panel Specification
Panel Type	Flexible AMOLED
Panel Size	13.2 inch
Backplane	Oxide TFT (GIP+ Pixel)
Resolution	2880×1920
Pixel Pitch	262 PPI (Real PPI)
Refresh rate	1~240Hz

The 13.2 inch full oxide flexible AMOLED display with MO-1 oxide TFT backplane technology has been demonstrated successfully shown in Figure 7. The detail specification of 13.2 inch AMOLED panel was shown in table 2. The 13.2 inch MO-1 full oxide flexible AMOLED display exhibited good brightness uniformity can be attributed the small Vth variation in Gen 6 glass area. The high mobility MO-1 metal oxide TFT backplane technology exhibited 262 PPI and wide refresh rate (1~240Hz) for middle size AMOLED display. This outcome indicated that MO-1 metal oxide TFTs is one of great potential backplane technology for large-generation AMOLED mass production.

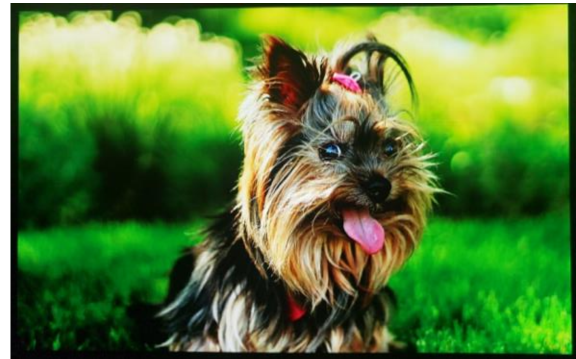

Figure 8. 12.6 inch full oxide AMOLED display with high mobility MO-2 metal oxide TFT backplane technology.

Table 3. The specification of 12.6 inch panel with MO-2 metal oxide TFT backplane technology.

	Panel Specification
Panel Type	Hybrid AMOLED
Panel Size	12.6 inch
Backplane	Oxide TFT (GIP+ Pixel)
Resolution	2880×1800
Pixel Pitch	273 PPI (Real PPI)
Refresh rate	1~240Hz

The 12.6 inch full oxide flexible AMOLED display with MO-2 oxide TFT backplane technology has also been demonstrated successfully shown in Figure 8. The detail specification of 12.6 inch AMOLED panel was shown in table 3. The high mobility MO-2 metal oxide TFT backplane technology exhibited 273 PPI and wide refresh rate (1~240Hz) for middle size AMOLED display.

The MO-2 oxide TFTs exhibited higher mobility than MO-1 metal oxide TFTs, which indicated the higher potential for narrow border can be achieved by using MO-2 metal oxide TFT backplane technology.

4. Conclusions

In this paper, we showed the MO-1 and MO-2 metal oxide TFT backplane technology with small Vth variation and good electrical reliability. Furthermore, The 13.2 and 12.6 inch middle-size AMOLED display have been demonstrated successfully by using MO-1 and MO-2 metal oxide TFT backplane technology, respectively. We believe that the MO-1 and MO-2 metal oxide backplane technology exhibit great potential for large-generation mass production applications. Besides, we have been developed the MO-3 metal oxide TFTs, which exhibited the higher mobility (55 cm^2/Vs) performance by using ALD technology for channel layer.

5. References

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