High Uniform and Stable Oxide TFT Devices with High Mobility for AMOLED Display

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Abstract

The high mobility metal oxide TFTs (thin film transistors) with high uniformity and stability has been developed. On Gen.6 glass, the high mobility oxide devices exhibited small Vth variations with different TFT structures and channel sizes. Furthermore, the 13.2 inch AMOLED panel with good display uniformity and narrow bezel has been fabricated successfully.

Author Keywords

Metal Oxide TFT, High mobility, OLED

1. Introduction

A backplane with different TFTs is the core part of an active matrix organic light emitting diode (AMOLED) display panel. At present, AMOLED has been commercially used in small size panels, such as watch and smart phone. With the increasing demands for larger size applications including IT displays, TFTs used in AMOLED should be achieved higher uniformity on large area. Thus, TFTs based on LTPS and LTPO became unsuitable even they have good performances in mobility and stability on small area [1]. In contrast, amorphous oxide semiconductor (AOS) TFTs are preferred, such as the one-based on $InGaZnO_4$ (IGZO), and promote the AMOLED commercialization for both large size panels and massive production in Gen.8 production lines [2, 3, 4].

The AOS TFTs exhibit relative small mobility which would be limited the panel performance such as narrow bezel, high refresh rate. Therefore, AOS TFTs have attracted extensive research in terms of high mobility performance improvement, however, it would bring more reliability issues owing to the large number of oxygen vacancy defect and higher carrier concentration with high mobility performance. In addition, the short channel effect of AOS TFTs is one of major challenges for different size TFTs integration in AMOLED display backplane applications [5, 6, 7].

In this work, we present a novel AOS TFT with high mobility, excellent stability and convergence performance even with short channel length. A middle size AMOLED flexible display was fabricated by the novel AOS TFT devices.

2. Experimental Section

We fabricated a self-aligned metal oxide thin-film transistor (TFT) on glass substrate in Gen.6 AMOLED factory, the TFT structure has shown in Figure 1. In the array process, the high mobility oxide layer is processed by magnetron sputtering (PVD), the insulate layer are deposited by chemical vapor deposition (CVD). To obtain stable and uniform devices, the TFT process recipes such as oxide PVD, CVD, annealing, etc. have been optimized. Three structures of top gate-1(TG with LS), top gate-2 (TG w/o LS), and dual gate (DG) with the different channel widths and lengths were employed separately in the TFTs. We conducted measurements on 36 sets of TFT TEGs at various locations on a G6-size glass substrate (1800x1500mm). The Id-Vg and BTS of different oxide devices were performed using a 4200 probe stage.

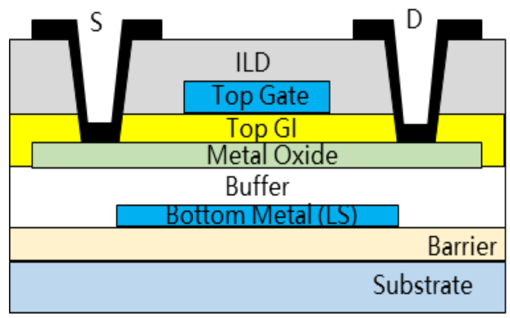

Figure 1. Self-aligned structure of high mobility oxide TFT

3. Results and Discussion

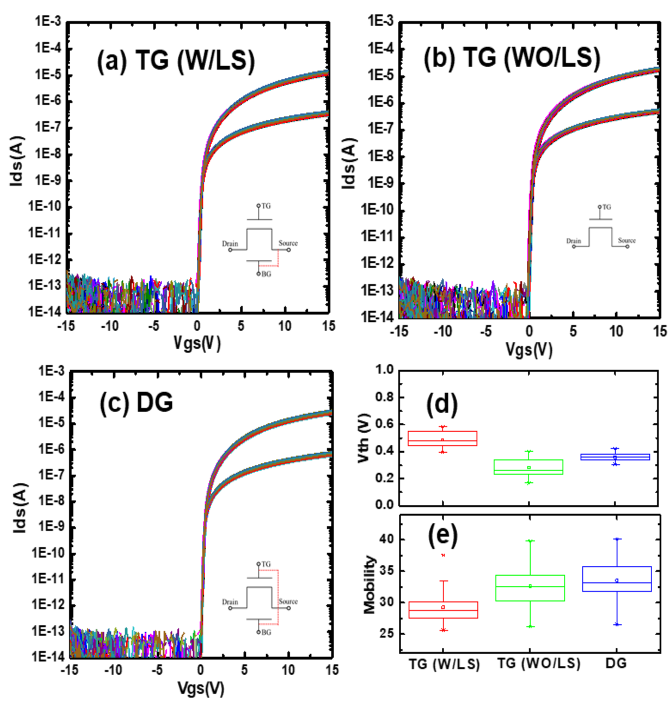

Figure 2. Id-Vg curves of high mobility oxide TFTs with different structures of (a) TG with LS, (b) TG w/o LS, and (c) DG. The Vth and mobility summary are shown in (d) and (e), respectively.

ISSN 0097-996X/25/5603-1406-$1.00 © 2025

Table 1. TFT parameters of Figure 2

TFT	Vth (V)	Mobility (cm^2/Vs)	SS (V/dec.)
TG with LS	0.48	29.3	0.17
TG w/o LS	0.28	32.6	0.13
DG	0.35	33.5	0.12

In AMOLED panel circuit, it is necessary to prepare devices with different structures on the same large board to meet different circuit requirements. However, to achieve optimal Vth uniformity for all the structures simultaneously is difficult, which need to optimize layer structure and process condition. Figure 2 (a) to (c) show the Id-Vg curves of devices with different structures after process optimization, including TG with LS, TG w/o LS, and DG, the three type devices has same channel width and length. As shown in Figure 2(d), all three structures achieved uniform distribution of Vth on the large board, and the device mobility reached 30 $cm^2/V.s$ as shown in Figure 2 (e). Among the three structures, SS of TG with LS TFTs is larger than that of TG w/o LS TFTs, and mobility is relatively smaller. The DG TFTs have the smallest SS, and the currents are the largest. The Vth distribution of DG TFTs is the best among the three structures. All the characteristics are listed in Table1.

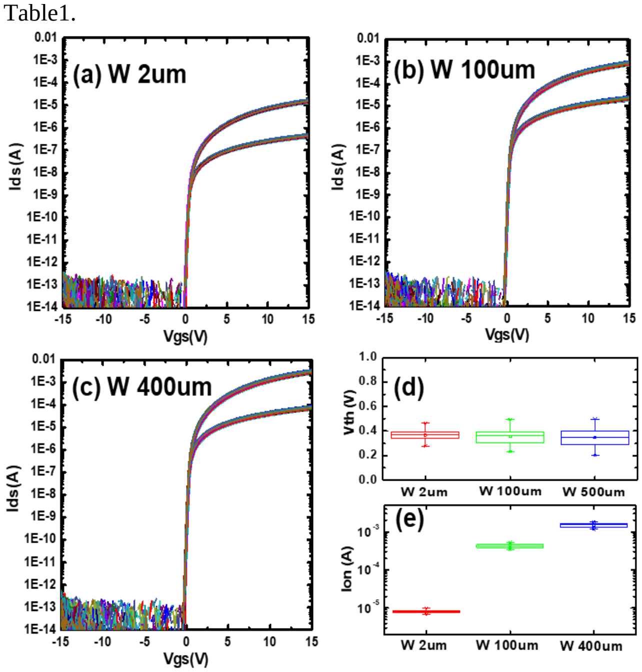

Figure 3. Id-Vg curves of high mobility oxide TFTs with different channel width of (a) 2um, (b) 100um, and (c) 400um. The Vth and Ion summary are shown in (d) and (e), respectively.

Figure 3 (a) to (c) show the Id-Vg curves of devices with different channel widths and a fixed channel length of 4um. When the channel width increases from 2um to 400um, the Ion increases nearly 200 times, as shown in Figure 3 (e), besides the Vth is basically unchanged, as Figures 3 (d) shown. The Vth Variation of devices are small on Gen.6 glass, which are based on 36 points' data for each type of devices. In a full oxide AMOLED circuit, TFTs of different channel widths are required. For instance, the GIP requires for a large width TFTs for obtaining large output current, while the pixel prefers a small width TFTs for smaller TFT size. Meanwhile, this circuit also pursues TFTs with a small Vth variation to simplify both design and fabrication. However, when channel width increases, Vth shifts negatively due to an increase in carrier amount. This requires for a process optimization to eliminate this unstable factor. The improved Vth uniformity in the larger channel width indicates that the high mobility oxide has a great advantage in the circuit design.

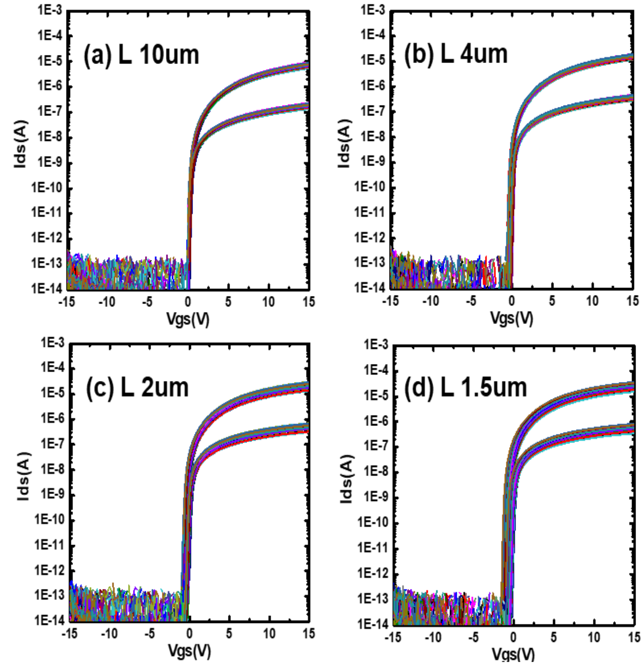

Figure 4. Id_Vg curves of high mobility oxide TFTs with different channel lengths of (a) 10um, (b) 4um, (c) 2um, and (d) 1.5um.

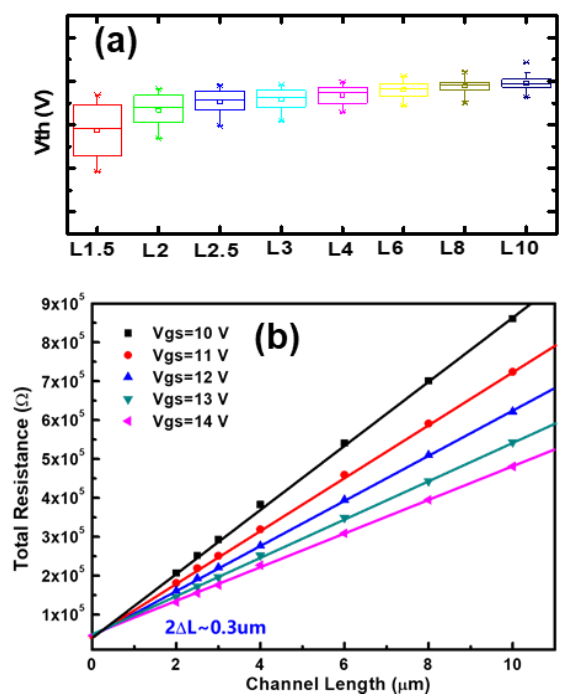

Figure 5. (a) The Vth with channel length from 10um to 1.5um; (b) the TLM analysis with different channel lengths devices.

Figure 4 illustrates the device performances of different channel lengths, where the channel width is fixed at 2um. The devices with channel lengths of 2, 4, and 10um all have positive Vth, and the Vth variation is small. Even for devices with channel length of 1.5um on Gen.6 glass, the average Vth also approaches to nearly 0V, and the Vth variation magnitude is acceptable. High mobility oxide TFTs usually have large carrier concentration. Which promotes the diffusion of charge carriers from the conductive region into the channel, making it challenging to optimize the characteristics of short channel devices [7]. As a result, a collective optimization in fabrication is executed, which includes the CVD, PVD, annealing and implant conditions, and realizes the enhanced short channel performance in the high mobility device.

The Vth distribution of 36 points and variations of the on-state resistance as a function of L (by transmission line method, TLM) are summarized in Figure 5(a) and (b), respectively. With the channel length decreasing from 10um to 2um, the Vth shifts negatively from 0.4V to 0.15V, with a small Vth difference of 0.25V. In circuit design, devices with different channel lengths are needed for certain functions with high output currents or higher SS values. This makes devices with small Vth differences between long and short channels more preferable. For backplane layout requirement, the short channel length of AOS TFTs is needed, which would be required a small carrier diffusion length in the channel region at source/drain edge. Figure 5(b) shows the calculated 2ΔL of 0.3um, which is a small value in high mobility device, and is related to the improved performance of short channel device shown in Figure 4.

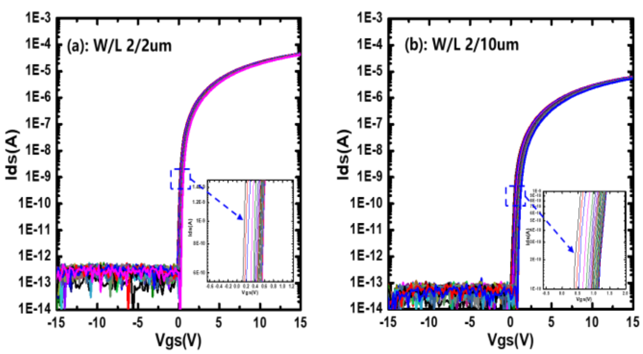

Figure 6. PBTS of high mobility oxide device, (a) width/length 2/2um, (b) width/length 2/10um.

Figure 6 shows the Vth shift under positive bias temperature stress (PBTS) with a gate bias voltage of +30V. The TFTs are tested at 60 ºC for 24 hours. The TFT channel width and length are set as 2/2um in Figure 6 (a) and 2/10um in Figure 6 (b), respectively. The short channel device has a Vth shift of 0.4V with a positive initial Vth. In the long channel device, the initial Vth is more positive when in comparison with the short channel device, but the Vth shift value is still relatively small at 0.8V. The small PBTS variation from channel length 2um to 10um is contributed by the small initial Vth difference. Due to the stable device performance under PBTS, the full-oxide AMOLED panels could be achieved with superior display performance.

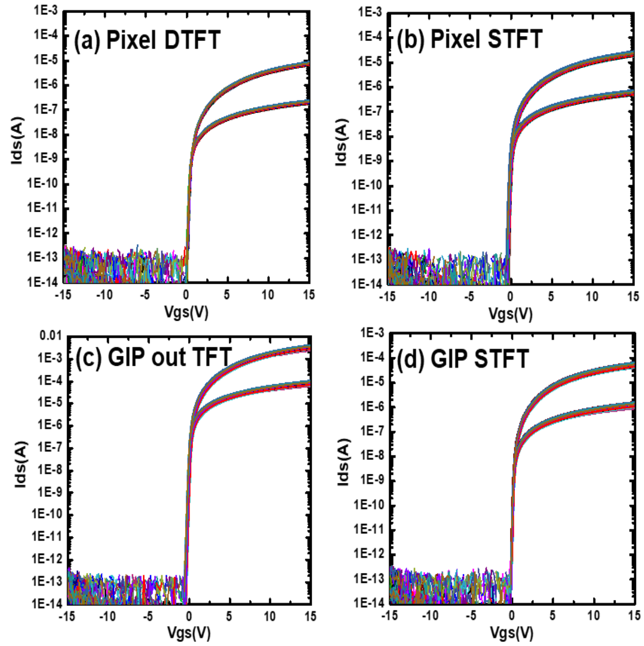

Figure 7. Device of different type TFTs in AMOLED panel, (a) Pixel driving TFT, (b) Pixel switching TFT, (c) GIP out TFT, (d) GIP switching TFT.

To accommodate the operational states of the TFT devices in the GIP and pixel circuits of the full-oxide AMOLED flexible display, we employed a variety of TFT structures and channel sizes in the DTFT, Pixel STFT, GIP OUT TFT and GIP STFT, respectively. As shown in Figure 7, different function of TFTs exhibited good uniformity of electrical performance. In AMOLED circuit design, the characteristic of DTFTs are required a large sub-threshold swing (SS), which facilitates low greyscale unfolding. On the other hand, the TFT sizes of STFTs should be small to increase resolution, and the GIP OUT TFTs should realize high output current. All of TFT devices are required small Vth variation and good electrical stability to obtain the good uniformity of optical performance and good long-term lifetime. Through process optimization, the high mobility oxide devices in this paper are achieved high uniformity with different TFT structures, channel widths and channel lengths. Besides, the Vth shift of 24h PBTS is very small. All of the above advantages can contribute to the AMOLED display with high PPI, narrow bezel, uniformity and stability.

Figure 8. 13.2 inch full oxide AMOLED panel with high mobility oxide TFT.

Finally, a 13.2inch full-oxide AMOLED flexible display with 262PPI has been successfully fabricated, as shown in Figure 8. Due to the high mobility and low leakage current of high mobility oxide TFTs, the AMOLED display can be driven at variable frequencies from 1 to 240Hz with narrow bezel. The AMOLED screen is exhibited a high-quality display effect, including uniformity across different brightness levels. Uniform and stable high mobility Oxide TFTs within a high quality full-oxide AMOLED display means high potential for mass production.

4. Conclusions

In this paper, we have implemented superior uniform and stable device performance with high mobility oxide. Good uniformity and small Vth variations in TFT devices are achieved with different structures, channel widths and channel lengths. Moreover, the small Vth shift under PBTS has been obtained, even when the channel length increases from 2um to 10um. Finally, the 13.2 inch flexible AMOLED panels with 262ppi and narrow bezel are fabricated. Due to the excellent performance of different types of devices used in panel circuits, the panel has achieved a good uniformity, and a large refresh range from 1HZ to 240HZ.

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