Oxide TFT as an Emerging Technology for Next Generation Display

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Abstract

In this paper, we describe the current status and issues of the oxide thin-film transistors (OTFTs), which attract much attention as an emerging new backplane technology replacing conventional silicon-based TFTs technologies. First, the unique benefits of OTFTs will be presented as a backplane for large-sized AMOLED including note-book PC, second TV and HD-TV. And then, the state-of-the-art transistor performance and uniformity characteristics of OTFTs will be highlighted. The obtained a-IGZO TFTs exhibited the field-effect mobility of 18 cm^2/Vs, threshold voltage of 1.8 V, on/off ratio of 10^9, and subthreshold gate swing of 0.28 V/decade. In addition, the world largest-sized 12.1-inch WXGA active-matrix organic light emitting diode (AMOLED) display is demonstrated using indium-gallium-zinc oxide (IGZO) TFTs.

1. Introduction

Among existing display technologies, active-matrix organic light-emitting diodes (AMOLEDs) provide the best solution to achieve ‘ultimate display’ due to their fast motion picture response time, vivid color, high contrast, and super-slim, lightweight nature [1,2]. In 2007, Samsung SDI has launched the first mass production of small-sized AMOLEDs for cell-phone and MP4 displays. The market is now burgeoning for mid-to-large-size applications, for example, note PC, monitor, and televisions. Samsung SDI’s recent exhibition of 14-inch and 31-inch full HD television prototype [3] and Sony’s commercialization of qFHD 11-inch TV (XEL-1) clearly show that the era of AMOLED TV is indeed nearby. Whereas the market is projected to reach 54 million units by 2011 [4], a number of hurdles in technology should be overcome for the mass production of mid-to-large sized AMOLED panels.

The biggest impediment to widespread adoption of AMOLED NPCs and TV is finding a way to produce them in mass quantities at affordable prices. The best strategy for this purpose is to increase the mother-glass size at least up to Gen. 5.5 (1300×1500mm), which corresponds to the most cost-effective backplane size for NPCs. However, the scaling-up of the production line causes several technological challenges. We describe the current statues and issue of TFT backplane, which is one of the most crucial technologies for the success of AMOLEDs.

First, amorphous silicon (a-Si) TFT is well-established and proven technology in liquid crystal display (LCD) industry nowadays. This technology has the advantage of good scalability up to Generation 8 and low cost process because it does not require the crystallization and ion doping process. In addition, the excellent uniformity of device performance including mobility and threshold voltage can be assured due to its amorphous nature. However, the mobility of a-Si TFT is quite low (~1cm^2/Vs), which may not be enough to drive the large-size and high-resolution AMOLED display. Furthermore, the device instability has been a long-time issue. For example, the threshold voltage of a-Si TFT is seriously shifted under constant current stress due to either the charge trapping into underlying gate dielectric or weak bonding break-up of silicon and hydrogen in a-Si thin film, leading to the image burn-out or serious image sticking (short life-time) in AMOLED display. This is the reason why a-Si TFT is hardly used as a backplane for AMOLED display.

On the other hand, low-temperature polycrystalline

Si (LTPS) TFT has the high mobility and excellent stability, which is in contrast compared to counterpart of a-Si TFT. The key process in fabricating LTPS TFTs is the crystallization methods that convert a-Si into polycrystalline Si. These methods can be classified to non-laser crystallization and laser annealing. Among non-laser crystallization, the simplest method is solid phase crystallization (SPC). But SPC requires 600ºC annealing for tens of hours, which makes it not suitable for large-area glass substrates. Other non-laser methods employ metal seed for crystallization, which may cause large leakage current in channel area. Among laser methods, excimer laser annealing (ELA; see Figure 1) has been the most widely used due to its excellent crystallinity, fast crystallization speed, and high mobility. In addition, ELA is already employed in mass-production, thus well-developed apparatuses are commercially available. However, ELA suffers from the narrow process window, high initial investment and maintenance cost. Moreover, the limitation in laser beam length and the laser beam instability are the major obstacles to use ELA on large-sized glass: the largest equipment available is applicable to Generation 4 (mother-glass 730 ×920mm). Finally, all LTPS TFTs including ELA technique suffer from the non-uniformity issue because of the existence of grain boundaries, which requires the complicate compensation unit pixel circuit such as 5 transistor + 2 capacitors leading to the loss of device yield.

Therefore, a natural question arises. “Is there any new TFT with the high mobility and excellent uniformity at the same time, which is suitable for the large-size AMOLED display? Amorphous oxide TFTs can be an attractive alternative solution to this question [5,6]. Amorphous oxide semiconductor (AOS) provides unique properties that combine the advantages of a-Si and LTPS TFTs. For example, amorphous oxide TFTs are free from the non-uniformity of mobility and threshold voltage, yet exhibits large carrier mobility (~10cm^2/Vs) and excellent subthreshold gate swing (down to 0.20 V/dec). Moreover, the channel layer can be fabricated by simple sputtering process. Therefore, large-size fabrication can be easily implemented up to Generation 8 without using expensive laser apparatus. The process route is essentially the same as a-Si TFTs so that the existing production line can be used without significant change. In addition, oxide TFTs can be deposited at room temperature, which, in principle, makes it possible the mass production of AMOLEDs on flexible plastic substrates or cheap soda-lime glass.

In this paper, we will discuss how the new technology of oxide TFTs allows simple solution for the challenges in backplane technologies for large-size AMOLED displays by reviewing the current issues in scaling-up the AMOLED backplanes. Then, the current challenges in oxide TFT fabrication are shown.

2. Results and Discussion

2.1 TFT Structure and Performance

Lithographically patterned Mo (200nm) on a SiO_2/glass substrate with a surface area of 370× 400mm^2 was used as the gate electrode. SiN_x (200nm) film as a gate dielectric layer was deposited by PECVD. The a-IGZO film with a thickness of 50nm was grown by rf sputtering on the SiO_2/glass substrate with a surface area of 370×400mm^2, using a polycrystalline $In_2Ga_2ZnO_7$ target at room temperature. The sputtering was carried out at a gas mixing ratio of Ar/O_2 = 65/35 and an input rf power of 450W. The atomic ratio of the IGZO film analyzed by inductively coupled plasma mass spectroscopy was In:Ga:Zn =2.2:2.2:1.0. After defining the a-IGZO channel using photolithography and wet etching, a SiO_x etch stopper was deposited by PECVD and, then, patterned by dry etching. Mo source and drain electrodes (200nm) were formed by sputtering and defined by photolithography, and then patterned by dry etching. Finally, the sample was subjected to thermal annealing at 350°C for 1hr. The transfer characteristics of the a-IGZO TFTs were measured at room temperature with an Agilent 4156C precision semiconductor parameter analyzer.

Figure 1 shows the schematic cross section of the IGZO TFTs, which have an inverted staggered bottom gate architecture with an etch stopper layer (ESL).

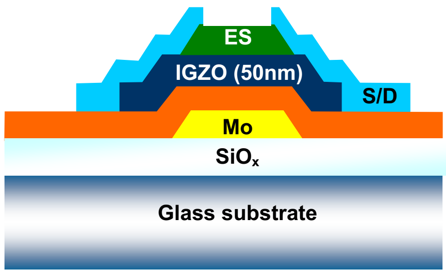

Figure 1. The schematic cross-section of a-IGZO TFT.

Figure 2 shows the representative transfer curve of the IGZO TFT with W/L=25/10μm, which was taken from the full array panel device rather than the individual test device without any passivation layer.

The fabricated device exhibited the high field-effect mobility of 18cm^2/Vs, excellent subthreshold gate swing of 0.28V/decade, and good $I_{on/off}$ ratio of 10^9, which corresponds to the state-of-the-art characteristics in any ZnO-based TFTs. We believed that these specifications of IGZO TFTs are enough to drive the high-resolution and large-area AMOLED panel.

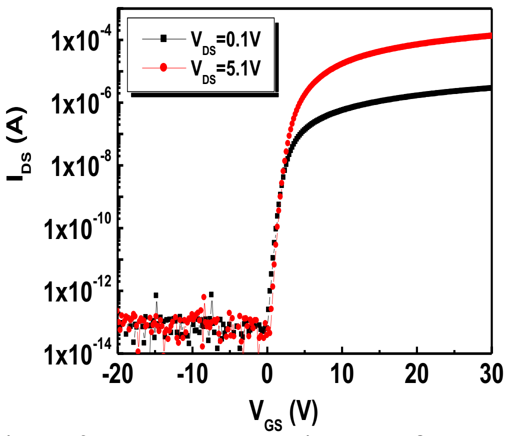

Figure 2. The representative transfer curve of the a-IGZO TFT with W/L=25/10μm with ESL.

The most difficult aspect of fabricating high-quality AMOLED displays is the presence of "muras" caused by TFT non-uniformities. The non-uniformities are caused by localized differences in TFT properties, which ultimately resulted in the variation in current levels supplied to the individual sub-pixel throughout the display. Therefore, another import figure-of-merit is the short-range and long-range uniformity of device performance. The short-range uniformity of oxide TFT is surprising: the representative standard deviations of threshold voltage (V_{th}) are less than 0.01V (not shown). The simple calculation predicts the non-uniformity in luminance of OLED diode to be less than 2%. This result suggests that ultra simple pixel circuit such as 2 transistors and 1 capacitor can be used for the design of AMOLED display, which will impact the device yield and cost very positively.

2.2 Stability of Oxide TFT

It is well known that the ZnO-based oxide transistor shows a huge V_{th} shift under positive gate voltage stress, which has been explained by two models: charge trapping or defect creation. In this study, we investigated the impact of the passivation layer on the stability of oxide TFT. It was found that the suitably passivated device did not exhibit any V_{th} shift. Figure 3 show the effect of the constant gate voltage stress on the suitably passivated device dielectric. The application of gate voltage stress (V_{GS}=15V, V_{DS}=0V, time=3600sec) resulted in positive V_{th} shift of only 0.2V. It should be noted that PMOS LTPS transistor showed approximately 0.1V shift in V_{th}. This result indicated that the stability of oxide transistor can be improved, which is comparable to that of LTPS TFT.

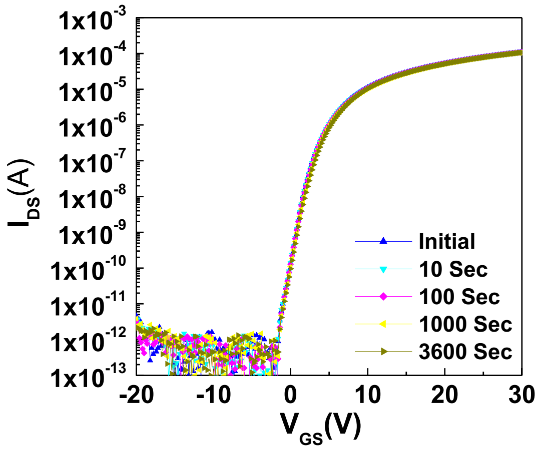

Figure 3. The effect of the constant gate voltage stress on the suitably passivated device.

2.3 The 12.1-inch AMOLED Prototype

In this work, we have successfully developed a full-color 12.1- inch WXGA AMOLED display, which was driven by a-IGZO TFTs backplane. The specification of 12.1-inch AMOLED display is summarized in Table 1. The display has the pixel number of 1280×RGB×768 with the resolution of 123ppi. Its sub-pixel pitch is the 69× 207μm^2 and the pixel element of 2Tr and 1cap. The channel length for driving transistor was designed to 10μm, but the kink effect, which appears in poly-Si TFT with the same channel length, was not observed in output characteristics. The scan driver was integrated on the panel and its functionality was successfully demonstrated. The bottom emission structure was adopted. The structure has the transparent anode, organic layers, and cathode on the TFT backplane. The OLED device structure consisted of hole injection layer (HIL), hole transport layer (HTL), RGB emitting layer (EML), electron transfer layer (ETL), electron injection layer (EIL), and cathode. The phosphorescent red and fluorescent green and blue were used as emitting materials. Figure 3 shows an image of the 12.1" WXGA AMOLED display.

Figure 4. The display image of 12.1" WXGA AMOLED display.

Recently, LG Electronic reported the 3.5-inch QCIF+ AMOLED prototype, which was driven by a-IGZO TFTs backplane [7]. We have also reported 4.1-inch transparent QCIF AMOLED display using a-IGZO TFTs in IMID 2007 [8]. So far, the research and development for a-IGZO TFTs has been focused on the demonstration of rather small-size AMOLED (<5inch). It should be emphasized that our prototype is the largest and highest resolution AMOLED display using a-IGZO TFTs backplane.

Items	Specification
Diagonal size No. of pixels	12.1 inch 1280 x RGB x 768
Sub pixel pitch	69 x 207 μm^2
Resolution	123 ppi
Panel size	283 x 181 mm^2
Pixel element	2Tr 1Cap
Gray	256 gray
Scan driver	Integration
Color coordinate	White (0.31, 0.31) Red (0.67, 0.32) Green (0.3, 0.65) Blue (0.15, 0.15)

Table 1. The specifications of 12.1" WXGA AMOLED display.

4. Summary

In summary, the state-of-the-art transistor performance and uniformity characteristics of Oxide TFT has been obtained. The attained a-IGZO TFTs exhibited the field-effect mobility of 18 cm^2/Vs, threshold voltage of 1.8 V, on/off ratio of 10^9, and subthreshold gate swing of 0.28 V/decade. Furthermore, the world largest-sized 12.1-inch WXGA active-matrix organic light emitting diode (AMOLED) display is demonstrated using indium-gallium-zinc oxide (IGZO) TFTs, indicating that a-IGZO TFT backplane technologies is an ideal candidate for large-sized AMOLED displays.

5. References

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