Layer Reduction of Hybrid TFT Towards 6.6 inch AMOLED Mass Production

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ABSTRACT

We have successfully implemented a novel process to reduce a metal and a dielectric layer of hybrid TFT. A process to reduce the Mo residue from the back channel of IGZO surface was also optimized. 6.6 inch AMOLED panels for smartphone with this new hybrid TFT process have been adopted for mass production.

1 INTRODUCTION

Organic light emitting diode (OLED) displays is required to reduce the power consumption and high refresh rate driving (generally 1Hz to 120 Hz) [1]. For high refresh rate driving, pixel circuits using p-type low temperature poly-silicon (p-LTPS) are the mainstream for OLED pixel circuit because of their high mobility. However, using only p-LTPS pixel circuit, it is difficult to realize a low refresh rate driving due to high off leakage current. In contrast, metal oxide semiconductors such as IGZO owing low off-state leakage current enable display frame-rate reduction. However, at present mass-producible metal oxide semiconductors are only available as n-type. To achieve a display with variable refresh rate (1-120Hz), a hybrid pixel circuit consisting LTPS and oxide TFT (IGZO) is effective [3]. There has been some display for smartphone and watch applications using the hybrid processed backplane, in which both LTPS and IGZO are used as semiconductor [1] [2] [5].

Unlike, LTPS only backplane, the hybrid TFT backplane need a contact between LTPS and IGZO. Therefore, the method to connect LTPS and IGZO each other with lower number of masks and simple structure is a key point of designing the hybrid process backplane for mass-production.

This paper report, the reduction of layers in a newly adopted backplane structure fabrication by an optimized hybrid process. We will describes a fabrication method to realize suitable IGZO/metal contact structure and uniform IGZO-TFT characteristics. To validate this optimized process for mass production, the uniformity and reliability of both IGZO and LTPS TFTs and the panel driving tests under harsh ageing conditions were evaluated. Finally, production of a smartphone (AQUOS R6) with this process-optimized hybrid backplane AMOLED display will be discussed.

2 EXPERIMENT

Figure 1 shows two types of hybrid structure. Figure 1A is the conventional hybrid structure and figure 1B is our proposed one. In figure 1, both LTPS and IGZO are connected to metal layer "SD", and they are connected with each other via "SD". As a result, a pattern density of "SD" will be high, and a part of bus line, such as global bus-line, has to be configured with additional metal layer "M2" which will make a process cost rise.

To overcome this problem, we propose a new hybrid structure shown in figure 1B. The difference from figure 1A is that IGZO is connected to metal layer "M1" directly, and LTPS and IGZO are connected via "M1" instead of "SD". In this case, a pattern density of "SD" is not increased by the connection between LTPS and IGZO, and pixels can be configured without using "M2" [3] [5].

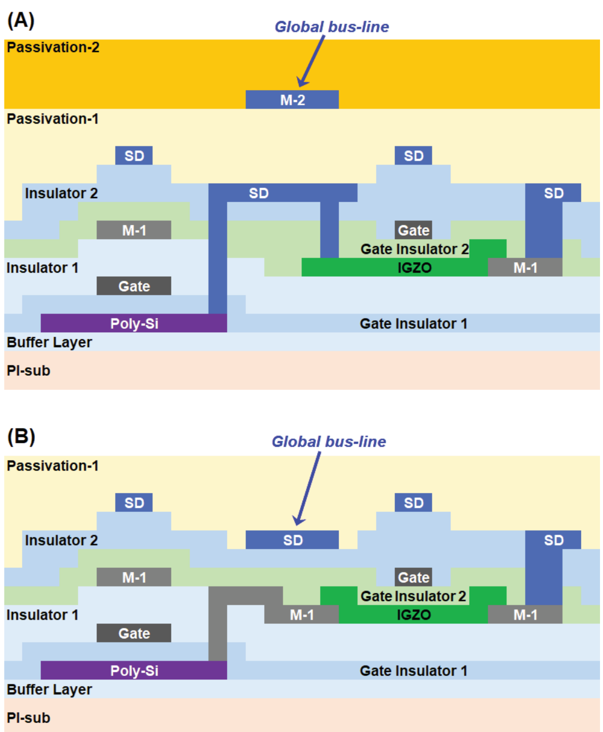

Fig. 1 (A) Conventional and (B) proposed hybrid TFT Structure.

3 RESULTS AND DISCUSSION

3.1 Optimization of IGZO/Mo contact

In terms of AMOLED panels, the process must be properly constructed, since an increase in contact resistance can lead to bright spots and/or mura. To achieve proper IGZO and Molybdenum (Mo) contacts, the IGZO film thickness and etching process must be optimized. In this structure, IGZO is stacked on top of Mo to form an IGZO/Mo contact structure. IGZO is a sputter-deposited oxide film and thinner than Mo metal, there is a concern about poor contact at the stack or disconnection due to etchant penetration. The IGZO stack area is determined by the IGZO film thickness and etching time, so the process must be optimized for these two points.

The electrical properties of the IGZO pattern was evaluated by measuring the resistance of the IGZO circuit TEGs (test element group) shown in figure 2A. In the IGZO circuit TEG, IGZO line pattern overlapped Mo island pattern. The width of IGZO pattern is 2.6 μm, the size of Mo island is 3.0 μm × 8.5 μm and the number of Mo island is 1,500, respectively. Figure 2B and 2C show the resistance plots of IGZO circuits as a function of cumulative probability. The horizontal axis is logarithm scale and the plots at the right edge of the vertical axis indicate high resistance and/or measurement failure (over the measurement range) due to the poor contact or disconnection of the IGZO pattern.

First, the IGZO film thickness was optimized. Figure 2b shows resistance plots for IGZO circuits with IGZO thicknesses of 10 nm, 20 nm, 30 nm, and 40 nm. The TEGs with IGZO thicknesses of 10 nm and 20 nm show that, some IGZO circuits are high resistance or unmeasurable, indicating that some IGZO circuits are almost or completely disconnected. On the other hand, when the IGZO thickness are 30 nm and 40 nm, the resistance of the IGZO circuits was uniform and low. This indicates that a 30 nm or thicker IGZO is necessary for good IGZO/Mo contact. Therefore, a IGZO film thickness of 30 nm was adopted for further process optimization.

Next, IGZO wet etching condition was optimized.Figure 2C shows the resistance plots of the IGZO circuit TEG with various etching time duration of 30 s, 35 s, and 40 s. When the IGZO was etched for 30 s the resistance of the IGZO circuit was uniform and low. However, as the etching time was extended, more and more IGZO circuits became high resistance or unmeasurable. With longer etching period, the over-etching time also increased, the etchant penetrated the interface between the photoresist and IGZO and/or between IGZO and Mo, and the IGZO circuit TEG was disconnected. These results indicate that an appropriate IGZO film thickness and etching time are very important to form IGZO/Mo contacts.

In addition, low IGZO/Mo contact resistance is desirable for AMOLED panels to operate in high-frequency and low-power modes. After optimizing the IGZO pattern process conditions, the electrical characteristics of the IGZO/Mo contacts were evaluated. Figure 3A shows a schematic of the IGZO/Mo contacts and Figure 3B shows the IGZO and Mo contact resistance as a function of cumulative probability. Measurements were performed at 9 points on a G4.5 glass substrate (730 mm x 920 mm) with a contact size of 2.6 μm x 4.0 μm. The resistance of the IGZO/Mo contacts was about 10 Ω with a standard deviation (σ) of 4.5, which is suitable IGZO/Mo contact resistance.

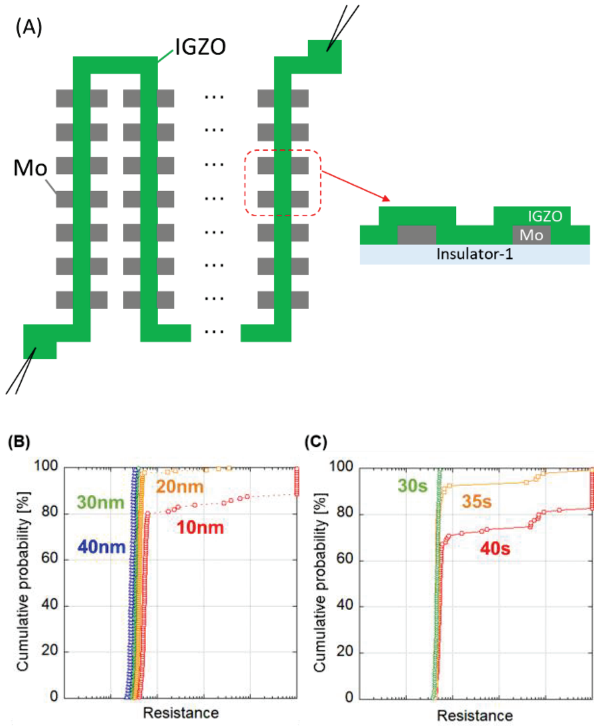

Figure 2. (A) Schematic illustration of the IGZO circuit TEG and probability plots of the resistance of IGZO circuit TEGs in the parameter of (B) IGZO thickness and (C) etching time.

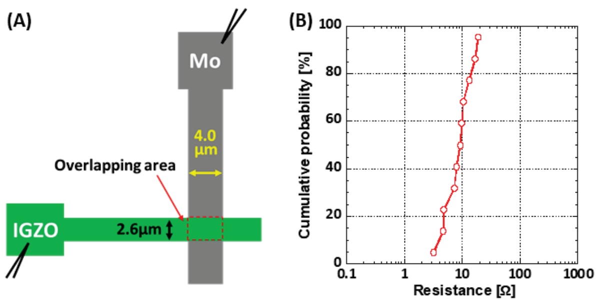

Fig. 3 (A) Schematic illustration of the IGZO/Mo contact structure and (B) probability plots of the resistance of IGZO/Mo contact.

3.2 Evaluation of Mo residue on the Insulator-1

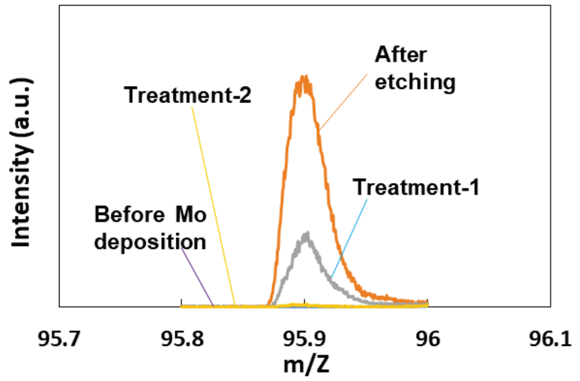

Fig. 4 TOF-SIMS spectrum of Mo on Insulator-1 surface before Mo deposition, after Mo etching and treatments.

This section discusses about the Mo process optimization. If Mo metal residue remain on the Insulator-1, it will cause several issues in the back contact IGZO-TFT structure as well as in the AMOLED panel operation. The metal residue on the Insulator-1 can cause line defects and/or bright spots in AMOLED panels that decrease total yields. Thus, a process for removing metal residue after Mo etching on the Insulator-1 is needed. Therefore, we conducted process optimization by evaluating the amount of metal residue measured by Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS). Figure 4 represents the element mapping image, showing the present of Mo at m/Z = 96. Compare with before Mo deposition (Before Mo deposition) after Mo etching (After etching) shows higher number of Mo counts. One of the technique to reduce residue is to increase Mo etching time. However, longer etching time might causes reduction of Insulator-1 thickness and deterioration of Mo metal taper shape which causes poor IGZO/Mo contact. Therefore, a process rather than etching time optimization is needed to reduce metal residue after Mo etching process.

Hence, an additional treatment process was developed. In this study, two types of plasma ashing were conducted as treatment process. As ashing gas, O_2 only and O_2 + Mo etching gas were used in the condition of treatment-1 and 2, respectively. Figure 4 shows that some metal residue remains after treatment-1, on the other hand, Mo residue completely removed after treatment-2. Optimized treatment process with O_2 and Mo etching gas (treatment-2) is suitable for removal of metal residue.

3.3 TFT characteristics

We evaluated the characteristics of TFTs fabricated as the new structure backplane process on the G4.5 PI/glass substrates with 13 points in same substrate. Figure 5A shows the 13 points of transfer characteristics of IGZO TFTs used in the hybrid pixel (T1, T2 and T7)

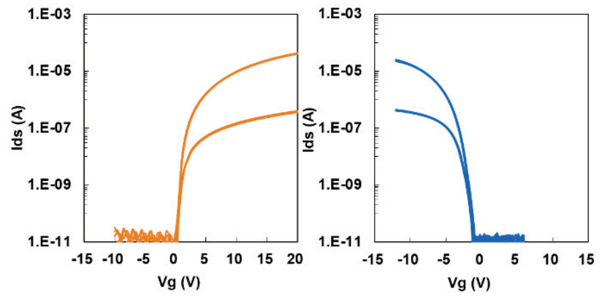

Fig. 5 Transfer characteristics of 13 points (A) IGZO pixel TFT with W/L = 2.6/4.0 μm, (B) p-LTPS TFT with W/L = 4.5/23.5 μm.

Table 1: Characteristics of IGZO and LTPS TFTs

	V_{th} [V]	σ of V_{th}	μ [cm^2/Vs]	I_{off} [A]
IGZO pixel	0.75	0.14	7.6	Under measurement limit
p-LTPS pixel	-1.43	0.08	84.3	~10^{-11}

with a channel width and length of 2.6 μm and 4.0 μm, respectively. The field effect mobility (μ_{FE}) of the IGZO TFT was 7.6 cm^2/Vs. The current flowing through the OLED device is controlled by applying voltage to the gate electrode of the driving transistor (T4), which is a p-LTPS TFT. Figure 5B shows the I_{ds}-V_{gs} characteristics of the T4 TFTs with a width and length of 4.5 and 23.5 μm, respectively. The field effect mobility (μ_{FE}) of the p-LTPS TFT was 84.3 cm^2/Vs. The median V_{th} of the IGZO pixel, IGZO GOA, and p-LTPS TFTs are 0.75 and -1.43 V, respectively. These results indicate that LTPS-TFTs and IGZO-TFTs with good characteristics and uniformity are realized in the new structure backplane process. The standard deviation (σ) of V_{th} for the p-LTPS, IGZO TFTs at GOA and IGZO pixel are 0.08 and 0.14 V, respectively. Characteristics of IGZO and p-LTPS TFTs are summarized in the table 1.

3.4 Reliability of AMOLED panels

The defects in the AMOLED panels accelerates with aging. Therefore, the aging properties of AMOLED panels are very important for the estimation of the lifetime [4]. We evaluated the reliability of the AMOLED panels fabricated by the optimized process.

Panels were aged both in dry (60˚C) and wet (40˚C, 95% humidity) condition. Figure 6A and 6B show the variation of the V_{pp} margin, V_{on}, and V_{off} margin, respectively with respect to the AMOLED panel ageing after 1000h. V_{pp}, V_{on}, and V_{off} margin for normal driving is secured even after driving more than 1,000 h. For dry ageing condition, V_{pp}, V_{on}, and V_{off} margin shift is 0.8 V, 0.8 V, and -0.6 V, respectively. For wet ageing condition, V_{pp}, V_{on}, and V_{off} margin shift is 1.0 V, 0.9V, and -0.7 V, respectively. This value is very small, ensuring sufficient reliability for mass production.

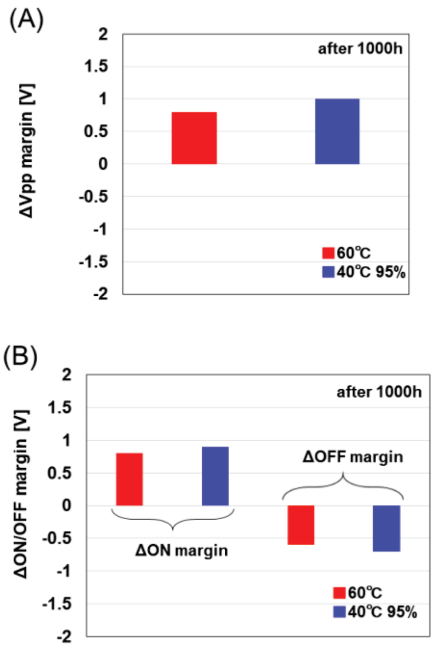

Fig. 6 AMOLED panel lifetime investigation of (A) ΔV_{pp} (B) Δon, off margin for 1,000 h. at 60 ˚C (dry) and 40 ˚C 95% (wet).

4 MASS PRODUCTION

The panel uses the described process technology has been adopted at “AQUOS R6”, a smartphone provided by Sharp Corporation as shown in the figure 7. The display specification of “AQUOS R6” are listed in the table 2. High quality display with high resolution (1260 x 2730) and wide range of drive frequency (1-120 Hz) was realized by using the process-optimized hybrid structure backplane.

Fig. 7 The product of the AMOLED display smartphone “AQUOS R6”

Table 2. Display specification of “AQUOS R6”

Parameters	Specifications
Screen diagonal	6.6 inch
Resolution	1260 × 2730
Drive frequency	1-120 Hz
Peak brightness	2,000 nit (cd/m^2)
Contrast ratio	20 million: 1

5 CONCLUSIONS

We have succeeded in optimizing a new structure of hybrid backplane technology with back contact IGZO-TFT and LTPS. We confirmed the Mo residue can be reduce and a good IGZO/Mo contact can be formed by treating Mo. The IGZO-TFTs uniformity and reliability were good enough for mass-production. The hybrid backplane AMOLED panel show high reliability under harsh condition.

Thus, this AMOLED pane has been adopted for mass market smartphone. We believe this novel process would be useful for AMOLED panel mass production with high quality and high yield.

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