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Article

Influence of Plasma Treatment to the Performance of Amorphous IGZO based Flexible Thin Film Transistors

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Abstract: Thin film transistors (TFTs) using In-Ga-Zn Oxide (IGZO) as active layer and the gate insulator was treated with NH_3 plasma and N_2O plasma, respectively, which is fabricated on flexible PI substrate in this work. The performance of IGZO TFTs with different plasma species and treatment time are investigated and compared. The experiment results show that the plasma species and treatment time play an important role in the threshold voltage, field-effect mobility, I_{on}/I_{off} ratio, sub-threshold swing (*SS*) and bias stress stability of the devices. The TFT with a 10 seconds NH3 plasma treatment shows the best performance; specifically, threshold voltage of 0.34 V, field-effect mobility of 15.97 cm^2/Vs, I_{on}/I_{off} ratio of 6.33×10^7, and sub-threshold swing of 0.36 V/dec. The proposed flexible IGZO-TFTs in this paper can be used as driving devices in the next-generation flexible displays.

Keywords: TFTs; IGZO; flexible; flasma treatment

1. Introduction

With the rapid development of AMOLED display technology, AMOLED display technology in compare to AMLCD display technology which exhibit more excellent properties, such as response faster, thinner, color is more brightly [1-3]. Glass substrate is the most commonly used in AMOLED and AMLCD display substrate manufacturing process, because of its high surface flatness, transparency, material stability, etc. At the same time, flexible display technology will be an important direction of display technology development now and in the future, but due to the hardness of large scale glass substrate which can't meet the requirements of flexible display substrate, the demand for flexible substrate technology were put forward. Plastic, metal film, ultra-thin glass, polyimide (PI) and other materials were used in flexible display research at present, and which can create a thinner, flexible display compared to traditional substrate technology [4-6]. At the same time, in order to develop the flexible display technology, traditional AMOLED display technology equipment and process technology were hoped used directly based on the traditional glass substrate fabrication process, except for low temperature process subject to special restrictions on flexible materials.

TFTs backplane active layer material technology progress past several years. Amorphous IGZO as a representative of oxide semiconductor TFT devices absorbed a lots of attention because of its higher field-effect mobility more than 10 cm2/Vs, lower of preparation process temperature, little affected by visible light and can be made into transparent devices, etc.[7-9]. So the IGZO based oxide semiconductor technology is optimum choice for flexible AMOLED display technology. However, according to the relevant reports [10-11], the electrical properties of the IGZO based TFTs devices characteristics, such as threshold voltage, sub-threshold swing (SS) and so on are affected by the process of film forming conditions. The threshold voltage is normally negative which can't meet the requirements of device drivers of AMOLED displays. Current of the IGZO based TFTs devices unable to be turned off or TFTs devices will be opened at low voltage are technical issues.

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In this latest work, the IGZO based TFTs devices with silicon nitride and silicon oxide layers stacked as gate insulator and NH_3 plasma surface treatment is demonstrated for the first time. In addition, N_2O plasma surface treatment is also used to distinguish the impacts of characteristic of the IGZO TFTs device (cf. Figure 1).

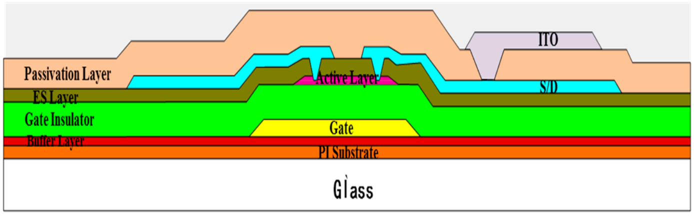
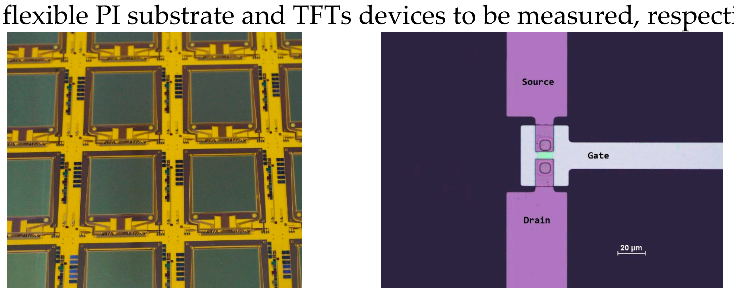


Figure 1. Schematic drawing of the flexible TFTs structures.

2. Materials and Methods

The fabrication of devices started by coating a 15-um PI flexible substrate on TFT glass substrate and baked for an hour at 220 °C. Then, a 150-nm silicon nitride was deposited by plasma-enhanced chemical vapor deposition (PECVD) at 220 °C capped with a 150-nm silicon oxide which deposited with the same temperature continuously as a buffer layer for flexible substrate. The buffer layer on one hand improved adhesion of deposited TFTs films, on the other hand, sequestered water vapor, oxygen effect of TFTs devices on the flexible substrate. TFTs device cross-sectional view of bottom gate TFT structure is as shown in Figure 1. Then, a 100-nm molybdenum and a 50-nm ITO were sputtered continually, patterned and wet etched for gate electrode. ITO layer used here for the dry etching stop layer to molybdenum which the dry etching selection ratio is about 1:3 of molybdenum and silicon oxide. Then, a 250-nm silicon nitride and 50-nm silicon oxide were deposited by PECVD at 220 °C for device gate insulator layer in order to increase the dielectric constant value. Then, gate insulator surface was treated 10 seconds by N_2O plasma, 10 seconds by NH_3 plasma, 120 seconds by NH_3 plasma, respectively. Controlled TFTs device is prepared as contrast. Then, a 50-nm amorphous IGZO was sputtered at room temperature, the sputtering power was at 300 W and gas flow of Ar and O2 were 50 sccm and 5 sccm. The active layer was patterned and etching for active island structure. Then a 200-nm silicon oxide was deposited by PEDVD at 250 ^{o}C as etching stop layer. It was patterned as via hole for the electrical contact between the active layer and source/ drain electrodes. The technology process of source and drain electrodes were sputtered and patterned using the same process as gate layer. Then a 200-nm silicon oxide was deposited as passivation layer. Dry etching was employed to form contact hole for electrical contact between pixel and drain. Finally, a 50-nm ITO film was sputtered at room temperature and patterned, etched as pixel patterns. In order to improve TFTs device stability, the substrate was annealed in atmosphere at 200 ^{o}C of 2 hours. The active layer channel of width (W)/ length (L) of TFTs TEG is 6 um/ 10 um. Figure 2 shows the top view of panel on the flexible PI substrate and TFTs devices to be measured, respectively.



(a) (b)

Figure 2. (a) Photo of panel manufactured on flexible PI substrate, TFTs TEG on the left of each shot of panel **(b)** Top view of TFTs TEG which the active layer channel of *W/L* is 6 um/10 um.

The fabricated IGZO-TFTs without plasma treatment were named NO. 1, with N_2O plasma treatment of 10 seconds were named NO. 2, and with NH_3 plasma treatment of 10 / 120 seconds were named NO. 3 / 4, respectively. Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

3. Results

The transfer characteristic curves of IGZO based flexible TFTs under various atmosphere treatment species and times were shown in Figure 3. Threshold voltage presenting an optimistic positive shift with the plasma treatment. It shown that the increased threshold voltage could be ascribed to the decrease of carrier density, the feature could be fit for most of the traditional display driver circuits. The I_{on}/I_{off} ratio of samples were measured at approximately 2.41×10^7, 2.46×10^7, 6.33×10^7 and 6.10×10^6 for sample NO. 1 to 4.

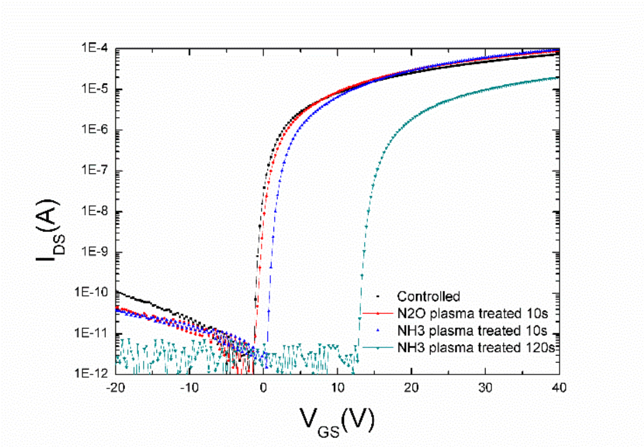
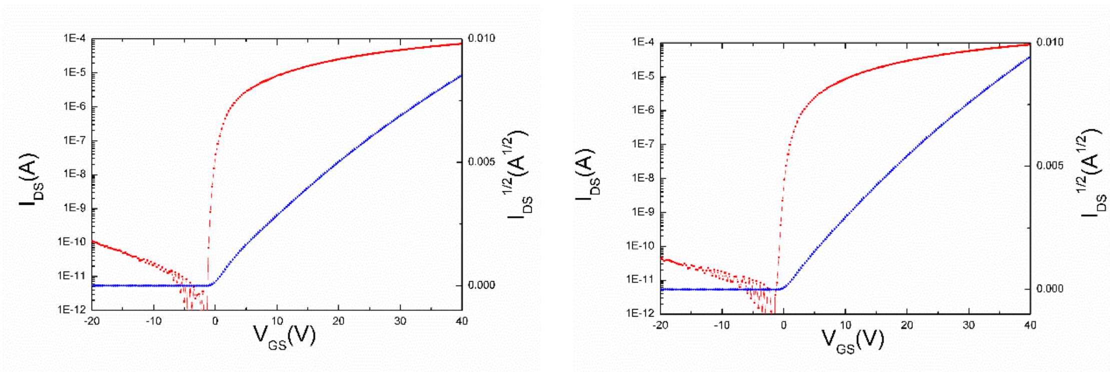


Figure 3. Transfer characteristic curves of IGZO based flexible TFTs after various treatment.

From the $I_{DS}^{1/2}$-V_{GS} curves shown in Figure 4, field-effect mobility (μ) and threshold voltage (V_{TH}) can be extracted according to the following expression:

$$I_{DS}=\frac{W}{2L}\mu C_i(V_{GS}-V_{TH})^2 \qquad V_{DS}>V_{GS}-V_{TH}, \tag{1}$$

Where C_i is the capacitance per unit of the gate insulator layer of 15.4 nF/cm^2. W and L are active layer channel width and length, V_{DS} and V_{GS} are source-drain voltage and gate-substrate voltage, respectively. The threshold voltage and field-effect mobility are of -4.42 V and 8.97 cm^2/Vs, -2.39 V and 12.49 cm^2/Vs, 0.34 V and 15.97 cm^2/Vs, 10.58V and 5.58 cm^2/Vs of the sample NO. 1 to 4, respectively.



(**a**) (**b**)

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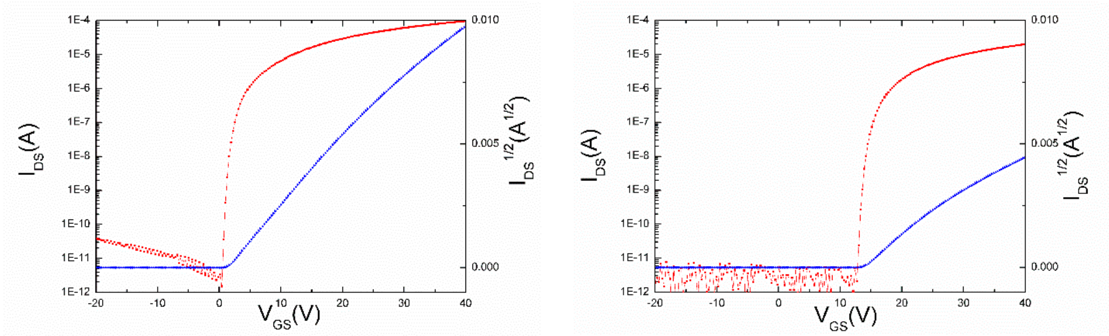


(c) (d)

Figure 4. Corresponding transfer characteristic I_{DS} versus V_{GS} at a fixed V_{DS}=10.1 V and the $I_{DS}^{1/2}$-V_{GS} curves of TFTs with various treatments. **(a)** Sample NO. 1. **(b)** Sample NO. 2. **(c)** Sample NO. 3. **(d)** Sample NO. 4.

Sub-threshold swing (SS) of samples can be calculated from the formula:

$$SS = \frac{dV_{GS}}{d\,(\log I_{DS})}\ , \tag{2}$$

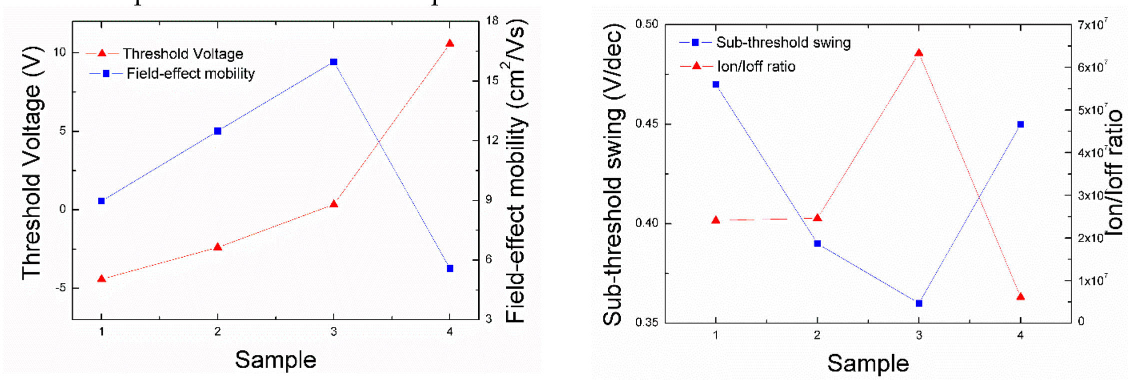
Here we measured the value of SS of 0.47 V/dec, 0.39 V/dec, 0.36 V/dec, 0.45 V/dec, respectively. Additional are listed in Table 1.

Table 1. Electrical characteristic of various treated TFTs

Samples	No.	V_{TH} (V)	SS (V/Dec)	μ (cm²/Vs)	I_{on}/I_{off}
Controlled	1	-4.42	0.47	8.97	2.41×10^7
N_2O treatment 10s	2	-2.39	0.39	12.49	2.46×10^7
NH_3 treatment 10s	3	0.34	0.36	15.97	6.33×10^7
NH_3 treatment 120s	4	10.58	0.45	5.58	6.10×10^6

As shown in Figure 5(a), the threshold voltage V_{TH} increased with the plasma treatment to the TFTs gate insulators. The V_{TH} of 0.34 V was obtained as the gate insulator treated by NH_3 plasma of 10 seconds, and increase to 10.58 V with treatment of 120 seconds. The IGZO-TFT with N_2O plasma treatment of 10 seconds shows a V_{TH} of -2.39 V.

As shown in Figure 5(b), sample NO. 3 shows a smallest SS value of 0.36 V/dec, which indicate that NH_3 plasma treatment has a positive effect on decreasing the trappings at the gate insulator/active layer interface. Sample NO. 4 with the NH_3 plasma treatment of 120 seconds shows a field-effect mobility of 5.58 cm²/Vs and a sub-threshold swing of 0.45 V/dec, indicating that the surface interface may be destroyed by the long times of ion bombardment. We concluded that the 10 seconds NH_3 plasma treatment is the optimal condition.



(a) (b)

Figure 5. (a) threshold voltage and field-effect mobility of samples NO. 1 to 4. **(b)** sub-threshold voltage and I_{on}/I_{off} ratio of samples NO. 1 to 4.

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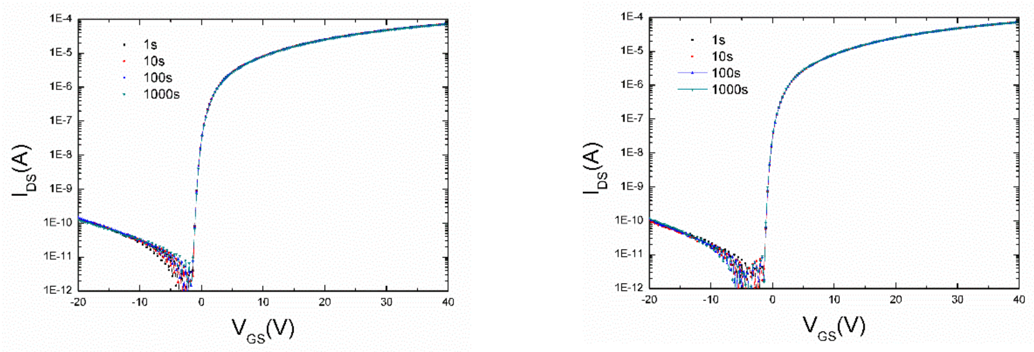
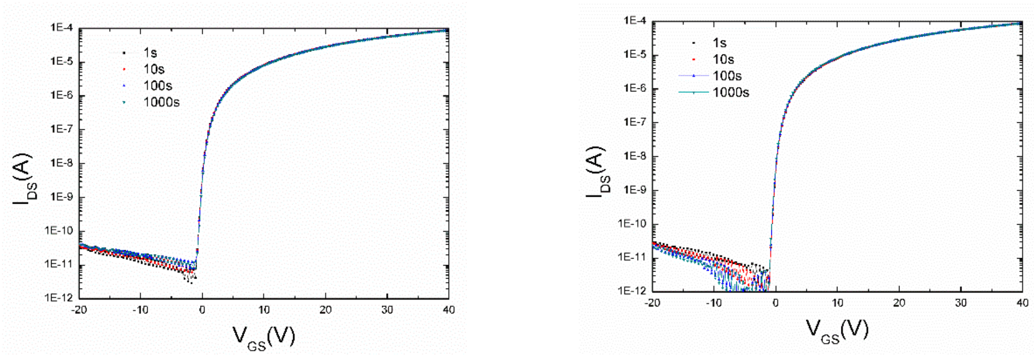


(a)



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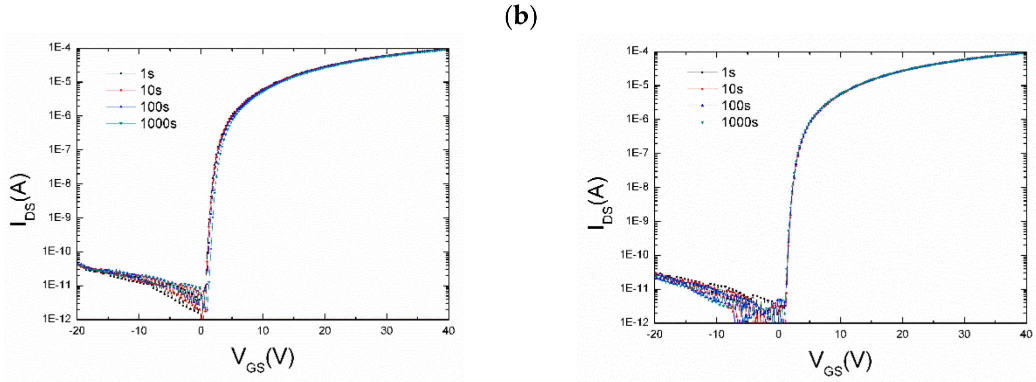
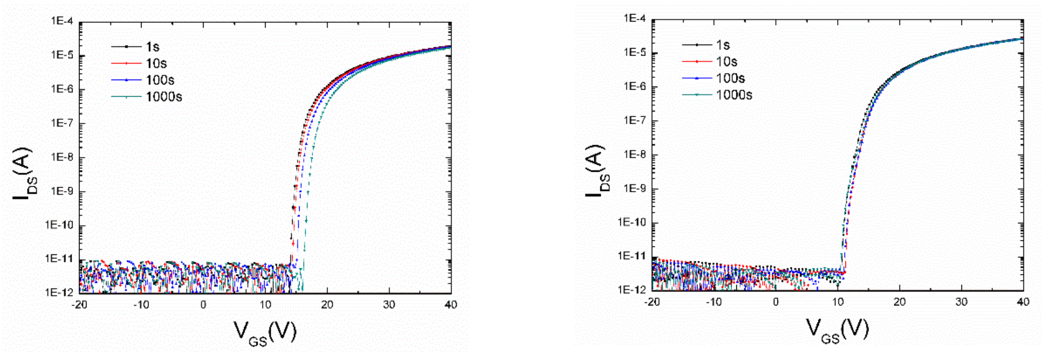


(c)



(d)

Figure 6. The transfer characteristic curves of IGZO based flexible TFTs. The gate bias voltage of 20 V at PBST and which of -20 V at NBST for 1000 seconds at room temperature, respectively. **(a)** PBST and NBST: No. 1. **(b)** PBST and NBST: No. 2. **(c)** PBST and NBST: No. 3. **(d)** PBST and NBST: No. 4.

Positive bias stress test (PBST) and negative bias voltage stress test (NBST) were carried out to further investigate the effect of plasma treatment on the stability of TFTs as shown in Figure 6. The gate bias voltage of 20 or -20 V was applied for 1000 seconds at room temperature in atmosphere. V_{GS} loaded on the TFTs continuously during the voltage stress process, which is two or three times more than typical driving voltage for display panels. The threshold voltage shifts under bias voltage stress is attributed to electron trapping between interface of the active layer and gate insulator. The TFT with a 10 seconds NH_3 plasma treatment also shows excellent stability under bias voltage stress. The threshold voltage shift were 0.12 V and 0.26 V after a 20 V and a -20 V gate voltage stressed for 1000 seconds, while the value for the sample NO. 1, 2 and 4 are -0.44 V and -0.92 V, -2.03 V and -1.16 V, 4.56 V and 0.14 V, respectively.

4. Conclusions

In conclusion, TFTs using IGZO as active layer and the gate insulator was treated with plasma, which are fabricated on flexible PI substrate in this work. TFTs treated by NH_3 plasma of 10 seconds shows the best performance than other samples under various treatment conditions, such as threshold voltage of 0.34 V, field-effect mobility of 15.97 cm^2/Vs, I_{on}/ I_{off} ratio of 6.33×10^7, and sub-threshold swing of 0.36 V/dec. The TFT with a 10 seconds NH_3 plasma treatment also shows stability under bias voltage stress test, the threshold voltage shift were 0.12 V and 0.26 V after a 20 V and a -20 V gate voltage stressed for 1000 seconds. Therefore, the NH_3 plasma treatment 10 seconds on the gate insulator of IGZO based flexible TFTs is an appropriately solution for improving the TFTs performance nowadays.

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Author Contributions: C.L. and Z.J. conceived and designed the experiments; S.X. and S.J performed the experiments; L.X. and Z.J. analyzed the data; D.X. contributed reagents/materials/analysis tools; C.L. wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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