A stable FHD display device based on BCE IGZO TFTs

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Abstract. In this work, the impact of the deposition process of the SiOx passivation layer on the electrical properties of the BCE IGZO TFTs has been studied. The ΔVth of the TFTs are 2.52 and -1.67 V under PBTS (60°C, 30 V) and NBITS (60°C, -30 V, 4500 nit) after 1 hour, respectively. The stability of these TFTs is verified in 32in FHD display devices, which still could display the picture properly after the 500-hour aging test at 60°C and 90% humidity. A stable FHD display device based on BCE IGZO TFTs was achieved.

1. Introduction
In recent years, the need for thin-film transistors (TFTs) with high performance has been increasing on account of the demand for ultra high definition display, low energy consumption and interactive functionality [1, 2]. A variety of technical solutions have been tried to meet these requirements. Amorphous metal oxide semiconductors (AOSs), such as Indium-Gallium-Zinc-Oxide (IGZO), Indium-Hafnium-Zinc-Oxide (IHZO) and Indium-Gallium-Tin-Oxide (IGTO), have attained great attention due to their excellent performance in cost-effective manufacturing process, good uniformity and reasonable low off-current [3-5]. Among them, IGZO has become an industry-standard channel layer because of its desirable mobility, high Ion/Ioff ratio and good long-time stability.

Many studies were performed to improve the performance of the IGZO TFTs. The back-channel etch (BCE) IGZO TFTs were prepared to reduce parasitic capacitance and production costs [6-8]. The effect of hot carriers on the IGZO lattice under high field strength has been studied [9]. The source/drain/active layer was split to improve TFT robustness under mechanical bending strain [10]. However, there are few reports on the influence of the deposition process of passivation layers on performance of IGZO TFTs.

In this paper, the deposition process of the SiOx passivation layer was studied to improve the performance of BCE IGZO TFTs. The TFTs were used in 32in full high definition (FHD) display devices. The stability of these devices was verified by an aging test in a high temperature and high humidity environment.

2. Experimental
The cross-sectional schematic of a BCE IGZO TFT is shown in Figure 1. At first, the Mo/Cu layer was deposited by sputtering and patterned as the gate material, followed by the deposition of SiNx and SiOx as the gate insulator (GI) equipped by a plasma enhanced chemical vapor deposition (PECVD). Then the IGZO layer was sputtered by magnetron sputtering system from the IGZO targets and further
patterned. Afterwards, the double layered source/drain (S/D) electrodes consisted of Mo/Cu were sputtered and patterned with a wet etchant. The channel width \((W)\) and length \((L)\) of the oxide TFTs were 10 µm and 5 µm, respectively. Subsequently, stacked SiO\(_x\)/SiN\(_x\) passivation layers and a PFA layer were deposited by PECVD and patterned. Finally, the indium tin oxide (ITO) layer was deposited by sputtering and patterned as the pixel electrodes.

![Figure 1 Cross-sectional schematic of the BCE IGZO TFTs.](image)

All electrical measurements were monitored by a Keithley 4200 source meter. The transfer characteristic curves were plotted measuring drain current \((I_d)\) by sweeping gate voltage \((V_g)\) from -25 V to 25 V with a drain voltage \((V_d)\) of 15 V. Electrical properties such as threshold voltage \((V_{th})\), field effect mobility \((\mu_{fe})\) and Sub-threshold Swing (SS) are extracted from the transfer characteristic curves. The \(V_{th}\) is calculated by extracting \(V_g\) when \(I_d\) reached 1 nA under the condition of \(V_d = 15\) V. The output characteristic curves were plotted measuring \(I_d\) by sweeping \(V_d\) from 0 V to 30 V with various \(V_g\) of 5, 10, 15, 20 and 25 V, respectively. For positive bias temperature stress (PBTS) measurements, a constant \(V_g\) of 30 V was applied at 60°C for 1 hour under dark conditions. For negative bias temperature stress under illumination (NBITS) measurements, a constant \(V_g\) of -30 V was applied at 60°C for 1 hour under illumination (4500nit). The TFTs were used in 32in FHD display devices to verify their stability and practicality in an aging test at 60°C and 90% humidity.

3. Results and discussion

The influence of the deposition process of the SiO\(_x\) passivation layer on the electrical properties of the BCE IGZO TFTs has been studied. Figure 2 represents the transfer characteristics of the TFTs with a SiO\(_x\) passivation layer deposited by different process parameters.

As shown in Figure 2(a), the curves illustrate a positive drift as the sputtering power of the SiO\(_x\) passivation layer increasing from 5 KW to 10 KW. The \(V_{th}\) of the TFTs are -0.6, 1.31, 2.77 and 3.86 V when the power are 5, 6, 8 and 10 KW, respectively. The increasing of \(V_{th}\) is due to the increase in the degree of oxidation of the IGZO active layer. As the sputtering power increases, the deposition rate of the SiO\(_x\) layer becomes slower (data not shown here), and the oxygen replenishment capacity of the SiO\(_x\) passivation layer is strengthened. When the degree of oxidation of the active layer is increased, free carriers in the film are reduced. Therefore, a higher voltage is required to turn the TFTs on.

A negative drift of the curves could be observed in Figure 2(b), as the SiH\(_4\) flow rate increasing from 1200 sccm to 1500 sccm. The \(V_{th}\) of the TFTs are 1.77, 1.31, -8.25 and -23.05 V while the SiH\(_4\) flow rate are 1200, 1300, 1400 and 1500 sccm, respectively. As the flow rate of SiH\(_4\) increases, the amount of H\(^+\) entering the IGZO layer increases, which improves the degree of conductivity of the IGZO layer. Thus, the \(V_{th}\) of the TFTs drifts to the negative direction.

Figure 2(c) shows the impact of the flow ratio of N\(_2\)O to SiH\(_4\) on the electrical properties of the TFTs. As can be seen from the figure that the electrical properties of the TFTs are less sensitive to the ratio. The \(V_{th}\) of the TFTs are 1.31, 1.39, 1.85 and 2.17 V, respectively, as the ratio are 30, 45, 60 and 75.

The SS could be calculated from the linear part of the \(\log(I_d)\) vs. \(V_g\) plot [11]:

\[
SS = \frac{\mu_{fe}}{S}
\]
\[ \text{SS} = \frac{dV_g}{d\log I_d} \quad (1) \]

And the \( \mu_{fe} \) could be estimated from the linear transfer characteristic curves by the equation [12]:

\[ \mu_{fe} = \frac{dI_d}{dV_g} \frac{L}{W C_{GI} V_d} \quad (2) \]

where \( C_{GI} \) is the GI capacitance per unit area. Table 1 presents the electrical parameters of the BCE IGZO TFTs with a sputtering power of 6 KW, a SiH\textsubscript{4} flow rate at 1300 sccm and a flow ratio of N\textsubscript{2}O to SiH\textsubscript{4} at 30. A \( V_{th} \) of 1.31 V, SS of 0.99 V/decade, \( I_{on}/I_{off} \) of \( 4.60 \times 10^7 \) and \( \mu_{fe} \) of 7.54 cm\textsuperscript{2}/Vs are observed.

| Parameter    | Unit      | Data     |
|--------------|-----------|----------|
| \( V_{th} \) | V         | 1.31     |
| SS           | V/decade  | 0.99     |
| \( I_{on}/I_{off} \) | \( \text{cm}^2/\text{Vs} \) | \( 4.60 \times 10^7 \) |
| \( \mu_{fe} \) | \( \text{cm}^2/\text{Vs} \) | 7.54     |

Figure 2 Transfer characteristic curves of the BCE IGZO TFTs with a SiO\textsubscript{x} passivation layer deposited by different (a) process power (b) SiH\textsubscript{4} flow rate and (c) flow ratio of N\textsubscript{2}O to SiH\textsubscript{4}.
Figure 3 Output characteristic curves of the BCE IGZO TFT with a SiO$_x$ passivation layer deposited with a sputtering power at 6 KW, a SiH$_4$ flow at 1300 sccm and a flow ratio of N$_2$O to SiH$_4$ at 30.

Figure 3 shows the output characteristics of the BCE IGZO TFTs with a SiO$_x$ passivation layer deposited with a sputtering power at 6 KW, a SiH$_4$ flow at 1300 sccm and a flow ratio of N$_2$O to SiH$_4$ at 30. The curves show clear pinch-off, which indicates that the electron transport in the TFTs is controlled by the $V_g$ and $V_d$.[13]

PBTS and NBITS were carried out, to further examine the long-time stability of the TFTs with a sputtering power at 6 KW, a SiH$_4$ flow at 1300 sccm and a flow ratio of N$_2$O to SiH$_4$ at 30. As shown in Figure 4(a), under the high temperature of 60°C and bias voltage of 30 V, the $V_{th}$ of the TFTs shifted from 1.36 V to 3.88 V after 1 hour. Figure 4(b) indicates that the $V_{th}$ drifts from 1.53 V to -0.14 V under NBITS (60°C, -30 V, 4500 nit) after 1 hour.

![Output characteristic curves](image)

Figure 4 (a) PBTS @ $V_g$=+30 V, T=60°C and (b) NBITS @ $V_g$=-30 V, T=60°C, I=4500 nit of the BCE IGZO TFT with a SiO$_x$ passivation layer deposited with a sputtering power at 6 KW, a SiH$_4$ flow at 1300 sccm and a flow ratio of N$_2$O to SiH$_4$ at 30.
The BCE IGZO TFTs using the above deposition process were applied in 32in FHD display devices. Figure 5 shows the circuit schematic of the gate on array (GOA), which integrates the gate drive circuit on the array substrate to reduce the size of the device frame. The GOA circuit is responsible for outputting the gate signal to the display area, so the stability of the TFTs in the circuit will determine whether the display is normal. In order to verify the stability of the device, an aging test was carried out. Figure 6 shows the photograph of the display device passed the 500-hour aging test at 60°C and 90% humidity. The device still displayed the picture properly, which proves that the TFTs used in the device have good stability and the deposition process of the SiO$_x$ passivation layer does improve the performance of BCE IGZO TFTs.

4. Conclusions
The BCE IGZO TFTs with a SiO$_x$ passivation layer were prepared on glass substrates. The influence of the deposition process of the SiO$_x$ passivation layer on the electrical properties of the BCE IGZO TFTs has been studied. The sputtering power and the flow ratio of N$_2$O to SiH$_4$ are positively correlated to the $V_{th}$ of the TFTs, while the SiH$_4$ flow rate and the $V_{th}$ are negatively correlated. A $V_{th}$ of 1.31 V, SS of 0.99 V/decade, $I_{on}/I_{off}$ of $4.60 \times 10^7$ and $\mu_{fe}$ of 7.54 cm$^2$/Vs are observed when the SiO$_x$ passivation layer has a sputtering power of 6 KW, a SiH$_4$ flow rate at 1300 sccm and a flow ratio of N$_2$O to SiH$_4$ at 30. The electron transport in the TFTs is controlled by the $V_g$ and $V_d$ as the output characteristic curves show clear pinch-off. In addition, the $V_{th}$ of the TFTs shifted from 1.36 V to 3.88 V after 1 hour under PBTS (60°C, +30 V), while the $V_{th}$ drifts from 1.53 V to -0.14 V under NBITS.
(60°C, -30 V, 4500 nit). The TFTs were applied in 32in FHD display devices. The device still displayed the picture properly after the 500-hour aging test at 60°C and 90% humidity. A stable FHD display device based on the BCE IGZO TFTs was achieved.

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