Stabilization of oxide-based thin-film transistors

Po-Tsun Liu, Yi-Teh Chou, Li-Feng Teng, Fu-Hai Li, and Han-Ping Shieh

Nitrogen doping improves the stability of indium gallium zinc oxide thin-film transistors and maintains the ease of device manufacture.

As development of flat-panel displays continues to grow, thin-film-transistor (TFT) technologies have been extensively used as switching devices or peripheral drivers in active-matrix LCDs (AMLCDs) and as pixel drivers for organic LEDs (AMOLEDs). However, amorphous silicon, which is conventionally used as the channel layer in TFT devices, faces development limitations because of physical drawbacks, such as low electron mobility, high photosensitivity, and Staebler-Wronski effects. For example, high-current-driving capabilities have made low-temperature polycrystalline silicon TFTs suitable candidates for pixel elements in AMOLEDs, despite issues related to device uniformity and high manufacturing costs.

To reduce the problems related to conventional silicon-based materials, novel semiconductors have been considered. The latter use amorphous oxide semiconductors as channel layers in TFT devices. They have attracted attention because of their high carrier mobility, low-temperature deposition, and optical transparency. Amorphous indium gallium zinc oxide films (a-IGZO) are the most obvious candidates. They have electrons as majority carriers, mainly because of the oxygen vacancies and interstitials created during the deposition process. The bonding structure of a-IGZO films causes the resultant TFT devices to exhibit high field-effect mobility. Nevertheless, a-IGZO TFT sensitivity to the environment hinders their performance under realistic operating conditions. This dependence is caused by absorption and desorption of oxygen species present in ambient air into the a-IGZO channel layer. This interaction changes the concentration of oxygen vacancies in the a-IGZO films and results in a shift of the TFT threshold voltage ($V_{th}$). Over time, this leads to a nonuniformity problem. To achieve reliable device operation, passivation methods have been developed to protect the a-IGZO channel from ambient-air interference. However, these methods require extrinsic channel-passivation layers, which need additional film-formation processes that usually degrade a-IGZO TFT-device properties.

In our recent work, we modified the a-IGZO films by doping them in situ with nitrogen during sputter deposition. Amorphous nitrogenated IGZO (IGZON) TFTs do not have backchannel passivation layers. They can exhibit electrical stability and device uniformity because of stoichiometry optimization and reduction of the concentration of inactive oxygen. This effectively simplifies the device-manufacturing process and enhances the reliability of a-IGZO-based TFT devices under realistic conditions.

We fabricated an inverted, staggered TFT structure on a silicon-wafer substrate. The active-channel layer for a 50nm-thick a-IGZON film was formed by DC sputtering deposition at room temperature using 100W power using a mixture of nitrogen ($N_2$) and argon ($Ar$) gas. The gas-flow ratios ranged from 0 to 0.2 and we applied a pressure of $5 \times 10^{-3}$ torr.

Figure 1(a) and (b) shows scanning-electron-microscopy images of a-IGZO and a-IGZON films sputter-deposited at a $N_2/Ar$ gas-flow ratio of 0.2. The grain size of $\sim$18nm-thick a-IGZON films is slightly larger than that of $\sim$14nm-thick a-IGZO films. These large grain sizes help to lower the films' resistivity. We measured the electrical characteristics and

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Table 1. Electrical parameters of thin-film-transistor (TFT) devices. The devices have amorphous IGZON (a-IGZON) channel layers that were shutter-deposited at $N_2$/Ar gas-flow ratios ranging from 0 to 0.2. The flow rate of Ar gas was fixed at 10 standard cm$^3$/min.

<table>
<thead>
<tr>
<th>$N_2$/Ar</th>
<th>$V_{th}$ (V)</th>
<th>S.S (V/dec)</th>
<th>$\mu$(cm$^2$/Vs)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>7.90</td>
<td>0.46</td>
<td>4.43</td>
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<tr>
<td>0.05</td>
<td>7.58</td>
<td>0.34</td>
<td>4.73</td>
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<tr>
<td>0.1</td>
<td>5.82</td>
<td>0.31</td>
<td>5.08</td>
</tr>
<tr>
<td>0.15</td>
<td>5.41</td>
<td>0.31</td>
<td>6.2</td>
</tr>
<tr>
<td>0.2</td>
<td>5.33</td>
<td>0.28</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Figure 2. Threshold voltage ($V_{th}$) shifts of a-IGZON-based TFT devices that were exposed to the atmosphere for several days. The error bars include five different measurements for each device.

uniformity of five a-IGZON TFT devices with different nitrogen concentrations (see Table 1). The threshold voltage and subthreshold swing (S.S) decreased with increasing nitrogen concentration, while the field-effect electron mobility ($\mu$, in units of cm$^2$/Vs) increased. We exposed the samples to the atmosphere and performed individual measurements both immediately and one, three, five, and seven days afterwards. Figure 2 shows the values of the $V_{th}$ shifts. The associated error bars include the effect of nitrogen incorporation on the a-IGZON TFT devices. It is clear that electrical stability and device uniformity improve with increasing nitrogen concentration.

In summary, we have proposed a novel a-IGZON-based TFT device that exhibits high electron mobility and reduced $V_{th}$ and S.S compared with conventional a-IGZO TFTs. The electrical reliability and ambient stability also improved because of the substitution of inactive oxygen with nitrogen atoms during film deposition. We plan to study the photosensitivity and electrical characteristics of these a-IGZON TFT devices under voltage-bias or constant-current stresses. This will help application of a-IGZON TFT devices to AMLCDs and AMOLEDs.

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References


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