Negative bias illumination stress instability in amorphous InGaZnO thin film transistors with transparent source and drain

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Ⅲ. 결론

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요 약

The investigations on the device instabilities in amorphous InGaZnO TFTs with metal (Ni) and transparent (ITO and InGaZnO) source and drain electrodes have been performed under negative bias stress (NBS), negative bias thermal stress (NBTS), negative bias illumination stress (NBIS) and negative bias thermal and illumination stress (NBTIS). From the measured device parameters in dark and under illumination conditions, a-IGZO TFTs with InGaZnO source and drain show an excellent device performances and lower device degradation than the devices with Ni and ITO source and drain under NBS and NBTS. However, amorphous IGZO TFTs with InGaZnO source and drain electrodes show more significant device degradation under NBIS and NBTIS. In order to explain our experimental results, we propose that the center responsible for the device instability is the process-related defects under NBS and NBTS, and the oxygen vacancy under NBIS and NBTIS, respectively.

I. 서론

Since InGaZnO thin film has a wide energy band gap (>3.0eV), the transparent electronic devices and display can be realized by the implementation of a-IGZO TFTs. However, a-IGZO TFTs with metal source and drain electrodes deteriorate the transparency. To improve the transparency, a-IGZO TFT with ITO source and drain electrodes was suggested but its transparency was known to be sensitive to the process conditions [1]. Currently, it was reported that the rapid thermal annealing treatment can convert InGaZnO film into an effective conductor so that a high performance a-IGZO TFT can be realized with InGaZnO source and drain electrodes [1-4]. As a side benefit of the transparency, the device fabrication convenience can be increased by the use of the same material target in the sputtering chamber for the active layer and the source and the drain electrodes.

Since the illumination through the transparent electronic devices can cause the device instability in conjunction with electrical bias and thermal stress, an experiment on the device degradation under NBS, NBTS, NBIS, and NBTIS is of great importance. The device degradation under NBS has been known negligible because of the lack of holes in channel [5]. However, the device degradation become significant under NBTS because the thermally induced holes from defect states are accumulated by negative gate bias and thus trapped in the gate dielectric layer [6]. Moreover, the oxygen vacancy plays a crucial role in the device instability under NBIS and thus the device degradation become the most significant under NBTIS [7-10]

The negative threshold voltage shift($\Delta V_{th}$) in a-IGZO TFT under illumination has been explained by three mechanisms including the oxygen photo-desorption model[11], the hole trapping model[12] and photon-transition model [8]. Although the origin of the negative
were electrodes. For instance, in the IGZO-A samples treated at a temperature of 300°C for 30 min, all samples were treated by conventional thermal annealing (CTA) at 600°C for 30 min. Ni and ITO were deposited for the source and drain electrodes. For the formation of InGaZnO source and drain electrodes, a 70-nm-thick InGaZnO layer was deposited with the same mole fraction ratio as an active layer using sputtering system. As shown in Table 1, the sample devices were split into four categories (Ni, ITO, IGZO-A, IGZO-B) according to source/drain electrode materials and the annealing treatments conditions. All devices were treated by CTA at 600°C for 30 min. IGZO-A and IGZO-B devices were treated additionally by RTP at 200°C for 30 sec and at 300°C for 30 sec, respectively. Could you tell which gas is used during annealing and what is the pressure. The passivation layer was not deposited in this work and the electrical measurements were performed at room temperature in air. For IGZO-A and IGZO-B devices the signal collection from the source and the drain electrodes was performed by connecting two tungsten probes to the source and the drain. The mask size of source and drain electrodes were 190 μm×250 μm. The channel lengths were ranging from 2 μm to 10 μm and the channel width was 20 μm. The measurements were made on more than 3 samples for each device, and the values were averaged.

2.1. Device fabrication

A highly doped p-type Si wafer was used to fabricate a bottom gate a-IGZO TFTs as shown in Fig.1. A 100-nm-thick of SiO₂ was grown by thermal oxidation as the gate dielectric layer. A 10-nm-thick InGaZnO film was deposited by RF sputtering system. The mole fraction ratio of InₓOᵧ:GaₓOᵧ:ZnO target was 1:1:1. After defining the active layer, all samples were treated by conventional thermal annealing (CTA) at 600°C for 30 min. Ni and ITO were deposited for the source and drain electrodes. For the formation of InGaZnO source and drain electrodes, a 70-nm-thick InGaZnO layer was deposited with the same mole fraction ratio as an active layer using sputtering system. As shown in Table 1, the sample devices were split into four categories (Ni, ITO, IGZO-A, IGZO-B) according to source/drain electrode materials and the annealing treatments conditions. All devices were treated by CTA at 600°C for 30 min. IGZO-A and IGZO-B devices were treated additionally by RTP at 200°C for 30 sec and at 300°C for 30 sec, respectively. Could you tell which gas is used during annealing and what is the pressure. The passivation layer was not deposited in this work and the electrical measurements were performed at room temperature in air. For IGZO-A and IGZO-B devices the signal collection from the source and the drain electrodes was performed by connecting two tungsten probes to the source and the drain. The mask size of source and drain electrodes were 190 μm×250 μm. The channel lengths were ranging from 2 μm to 10 μm and the channel width was 20 μm. The measurements were made on more than 3 samples for each device, and the values were averaged.
2.2. Results and discussion

Fig. 2 shows the comparison of the transfer curves with source/drain materials and RTP treatments. The order of magnitude of ON current (ION) is Ni>ITO>IGZO-B>IGZO-A. From the comparison of IGZO-A and IGZO-B devices, the RTP treatment at higher temperature can convert IGZO-B devices into more conductive materials. This has been known that the free electron concentrations are increased due to the increased oxygen vacancies which are resulting from the oxygen out-diffusion during RTP treatment [1]. From the X-ray photoelectron spectroscopy (XPS) spectra with (IGZO-B device) and without RTP treatment (Ni and ITO devices) are shown in Fig. 3, one can clearly see that the oxygen concentration was decreased from 71.3% to 58% but the oxygen vacancy one was increased from 28.7% to 42% after RTP treatment. It is remarkable that IGZO-A and IGZO-B devices show steeper subthreshold slope (S) than Ni and ITO devices. The result means that the interface traps created during device fabrication were reduced through the additional RTP treatment in IGZO-A and IGZO-B devices.

To compare the source and drain parasitic resistances (RSD), a transmission line method (TLM) has been used [14], which involved plotting the total ON-resistance (RON) of a-IGZO TFTs as a function of the channel lengths. Fig. 4 shows a plot of RON as a function of channel lengths of IGZO-B devices at VDS=1.0 V. From this plot, we can get rich information about both intrinsic and parasitic device characteristics. RSD can be extracted from the intercept of y-axis and the difference (ΔL) between the effective channel length (Leff) and the physical channel length (LM) can also be extracted from the intercept of x-axis. The extracted RSD is about 86 KΩ and ΔL was −2.9 μm. An interesting aspect is negative ΔL in IGZO-A and IGZO-B devices. The negative ΔL indicates that the effective channel length is larger than the physical channel length. This probably means that the actual current flux is much more spread out over the source and drain-to-channel overlap region [15]. The current injection point moves way from the channel edge toward the source and the drain electrodes, resulting in larger RON and a negative ΔL. By plotting the reciprocal of the slope, (RONW/ΔL)=1 versus VG, the field effect mobility (μeff= 10.3 cm2/Vsec) was extracted from the slope of a linear least-square curve fit. The summary of measured device parameters was shown in Table 2. As expected, the order of magnitude of RSD is IGZO-A N IGZO-B N ITO N Ni. The order of magnitude of effective mobility is Ni N ITO N IGZO-B N IGZO-A.

From the time dependence of ΔVTH under NBS as shown in Fig.5, Ni and ITO devices show more significant degradation than IGZO-A and IGZO-B devices. The VTH was defined as VGS required to reach a drain current of 2.5μA×L/W[μA]at VDS=1.0 V. Since the hole concentration is so small in InGaZnO film, the device degradation under NBS is known to be negligible [5]. The significant ΔVTH of Ni and ITO devices may be attributed to the non-optimized device process in this work. The smaller ΔVTH of IGZO-A and IGZO-B devices than those of Ni and ITO devices are speculated to be process-related point
defects, which may be donor states located 0.11 eV below the conduction band[16], that were reduced by an additional RTA treatment in IGZO-A and IGZO-B devices.

From the temperature dependence of $V_{TH}$ as shown in Fig. 6, the $V_{TH}$ linearly decreases with the temperature with a temperature coefficient of $-34 \text{ mV/°C}$ and $-24 \text{ mV/°C}$ for ITO and Ni devices. The reason for smaller temperature coefficients in IGZO-A and IGZO-B devices than those in Ni and ITO devices is believed due to the reduced localized states through an additional RTP treatment. At elevated temperature, the reduction of $V_{TH}$ is resulted from the escaped free electrons from the localized states [17].

Fig. 7 shows the comparison of NBTS-induced $\Delta V_{TH}$ as a function of stress temperatures. The device degradation is more significant in Ni and ITO devices than in IGZO-A and IGZO-B devices. Under NBTS, it has been known that the thermal induced holes from process related defects are injected into the gate electrode by the negative VG and thus trapped at the interface between the channel and the gate dielectric layer [6].

To investigate the larger $\Delta V_{TH}$ of Ni and ITO devices than those of IGZO-A and IGZO-B devices under NBS and NSTS, the effective barrier energy height that holes in channel need to overcome before they can inject into the gate dielectric layer was extracted using a stretched- exponential equation for $\Delta V_{TH}$ [18]. Fig. 8 shows a plot of the characteristic trapping time as a function of $1/KT$ with different source and drain materials. The extracted average effective barrier energies ($E_t$) are $E_t= 0.55 \text{ eV}$ for Ni, $0.59 \text{ eV}$ for ITO, $0.65 \text{ eV}$ for IGZO-B, and $0.7 \text{ eV}$ for IGZO-A devices, respectively. The lower degradations of IGZO-A and IGZO-B devices than Ni and ITO devices could be explained by higher effective barrier energy which may be resulting from the oxygen out-diffusion. From the measurement results, we can conclude that the process-related defects and the effective barrier energy are the dominant factors in the device degradation under NBS and NBTS.

Table 3 shows the summary of measured device performance parameters under illumination. A white halogen lamp ranging from 500 nm to 700 nm wavelength and with the intensity of 0.22 mW/cm² was used as a light source. The S of ITO device was slightly increased under illumination. Due to the increased electron concentration from the electron-hole pair generation under illumination, $I_{ON}/I_{OFF}$ and $\mu_{eff}$ are increased. From the comparison of RSD in dark and under illumination, the reduction of RSD in IGZO-B device is the most significant. The increased $\mu_{eff}$ in IGZO-A and IGZO-B devices under illumination is due to the extended accumulation layer which broadens the channel into the source and drain regions.

Fig. 9 shows the comparison of the time dependence of $\Delta V_{TH}$ with source/drain materials and RTP treatments under NBIS. It is remarkable that the $\Delta V_{TH}$ of IGZO-B device is less than those of Ni and ITO devices at early stress time but it increases rapidly and becomes the most significant. This result indicates that the oxygen vacancy plays a crucial role in determining of the device instability under NBIS. The oxygen vacancy which is a deep state can be excited to positively double charged state by light irradiation as reported in literature [8, 19]. The oxygen vacancy roles under NBIS can be also confirmed from the more significant $\Delta V_{TH}$ in IGZO-B device than IGZO-A device.
From NBTIS-induced $\Delta V_{TH}$ as a function of stress temperatures as shown in Fig.10, IGZO-B device shows the most significant degradation under NBTIS. The result means also that the oxygen vacancy plays a crucial role in determining the device instability under illumination stress. In order to explain our experimental results, we propose that the center responsible for the device instability is the process-related defects under NBS and NBTS, and the oxygen vacancy under NBIS and NBTIS, respectively.

Table 1 Thermal treatment conditions

<table>
<thead>
<tr>
<th>Device</th>
<th>Thermal treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni and ITO</td>
<td>CTA (600 °C for 30min)</td>
</tr>
<tr>
<td>IGZO-A</td>
<td>CTA+RTP at 200 °C for 30sec</td>
</tr>
<tr>
<td>IGZO-B</td>
<td>CTA+RTP at 300 °C for 30sec</td>
</tr>
</tbody>
</table>

Table 2 Summary of measured device performance parameters ($L/W=10/20 \mu m$).

<table>
<thead>
<tr>
<th></th>
<th>IGZO-A</th>
<th>IGZO-B</th>
<th>Ni</th>
<th>ITO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{ON}/I_{OFF}$</td>
<td>7.1</td>
<td>1.0E+07</td>
<td>3.8E+08</td>
<td>3.9E+08</td>
</tr>
<tr>
<td>$S$ (V/dec)</td>
<td>0.29</td>
<td>0.30</td>
<td>0.54</td>
<td>0.55</td>
</tr>
<tr>
<td>$L_{eff}(\mu m)$</td>
<td>19.8</td>
<td>12.9</td>
<td>9.5</td>
<td>9.6</td>
</tr>
<tr>
<td>$R_{SB}(\Omega cm)$</td>
<td>226</td>
<td>170</td>
<td>2.2</td>
<td>12</td>
</tr>
<tr>
<td>$\mu_{eff}(cm^2/V*sec)$</td>
<td>5.0</td>
<td>10.3</td>
<td>13.9</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Table 3 Summary of measured device performance parameters under illumination($L/W=10/20 \mu m$).

<table>
<thead>
<tr>
<th></th>
<th>IGZO-A</th>
<th>IGZO-B</th>
<th>Ni</th>
<th>ITO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{ON}/I_{OFF}$</td>
<td>7.1E+06</td>
<td>1.6E+08</td>
<td>1.0E+08</td>
<td>1.9E+08</td>
</tr>
<tr>
<td>$S$ (V/dec)</td>
<td>0.27</td>
<td>0.34</td>
<td>0.57</td>
<td>0.79</td>
</tr>
<tr>
<td>$L_{eff}(\mu m)$</td>
<td>20.5</td>
<td>14.3</td>
<td>9.6</td>
<td>9.7</td>
</tr>
<tr>
<td>$R_{SB}(\Omega cm)$</td>
<td>186</td>
<td>128</td>
<td>1.6</td>
<td>5.8</td>
</tr>
<tr>
<td>$\mu_{eff}(cm^2/V*sec)$</td>
<td>5.1</td>
<td>11.3</td>
<td>14.4</td>
<td>13.2</td>
</tr>
</tbody>
</table>
Fig.1 Schematic diagram of fabricated a-IGZO TFT with Si bottom-gate.

Fig.2 Comparison of the transfer curves with source/drain materials and RTP treatments at $V_{DS} = 1.0V$. 

$I_{DS}(A)\rightarrow 10^{-4}$

$L/W=10/20\mu m$

$V_{DS} = 1V$
Fig. 3 XPS spectra on InGaZnO surface of Ni and ITO devices (a) and IGZO-B device (b).

Fig. 4 Plot of $R_{ON}$ as a function channel length for IGZO-B TFTs with $W=20\mu m$. 
Fig. 5 Comparison of the time dependence of $\Delta V_{TH}$ with source/drain materials and RTP treatments under NBS.

![Graph showing time dependence of $\Delta V_{TH}$](image)

Fig. 6 Comparison of the temperature dependence of $V_{TH}$ with source/drain materials and RTP treatments.

![Graph showing temperature dependence of $V_{TH}$](image)
Fig. 7 Comparison of the temperature dependence of $\Delta V_{\text{th}}$ with source/drain materials and RTP treatments under NBTS.

Fig. 8 Characteristic trapping time $\tau$ as a function of $1/\text{KT}$.
Fig. 9 Comparison of the time dependence of $\Delta V_{TH}$ with source/drain materials and RTP treatments under NBIS.

Fig. 10 Comparison of the time dependence of $\Delta V_{TH}$ with source/drain materials and RTP treatments under NBTIS.
Ⅲ. 결론

a-IGZO TFTs with InGaZnO source and drain electrodes show excellent device performances and the lower device degradation than devices with Ni and ITO source and drain under NBS and NBTS. The lower degradation is attributed to reduce process-related defects and larger effective barrier energy. However, a-IGZO TFTs with InGaZnO source and drain electrodes, which was treated by controlled RTP, showed the highest device degradation under NBIS and NBTIS. This result can be attributed to the ionization of the oxygen vacancies by light illumination. From our experimental results under various stress conditions, we conclude that the center responsible for the device instability is the process-related defects under NBS and NBTS, and the oxygen vacancy under NBIS and NBTIS, respectively.

Acknowledgements

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참 고 문 헌

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