Effect of Source/Drain Electrodes on Electrical Properties of Silicon-Tin-Oxide Thin-Film Transistors

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Figure S1. X-ray reflectivity (XRR) curves for a-STO films.

Table S1. The properties (density, thickness and roughness) of a-STO films.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Density (g/cm³)</th>
<th>Thickness (nm)</th>
<th>Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.21</td>
<td>5.062</td>
<td>0.669</td>
</tr>
<tr>
<td>2</td>
<td>6.198</td>
<td>5.06</td>
<td>0.623</td>
</tr>
<tr>
<td>3</td>
<td>6.138</td>
<td>5.043</td>
<td>0.671</td>
</tr>
</tbody>
</table>

Figure S2. (a) The schematic diagram of a-STO TFT. (b) Cross-sectional high resolution transmission electron microscope (HRTEM) image and elements distribution detected by Energy-dispersive X-ray spectroscopy (EDS) mapping scan for a-STO TFT.
Figure S3. (a) The cross-sectional transmission electron microscope (TEM) image and (b) elements distribution detected by Energy-dispersive X-ray spectroscopy (EDS) line scan for a-STO TFT.

Figure S4. (a) The work function of a-STO film (200nm) measured by X-ray Photoelectron Spectroscopy. (b) Theoretically, the energy band diagram of a-STO film contacted with different electrodes: ITO and Mo. The work functions of ITO, Mo and a-STO are 4.5 eV, 4.6 eV and 5.38 eV, respectively.
Figure S5. I-V curves of a-STO film contacted with different electrodes: (a) ITO and (b) Mo. The linear I-V curve of TFT with ITO or Mo contact indicated that Ohmic contact was formed at the electrode/a-STO interface.

**The importance of DOS in AOS device:**

In AOS devices, the subgap density of states (DOS) is an important parameter which plays a major part in controlling the mobility, the operation voltage and subthreshold swing of TFTs. The TFT mobilities are deteriorated by the subgap density of states (DOS), as roughly expressed by

$$\mu_{FE} = \mu \frac{N_{GS} - N_T}{N_{GS}}$$

where $N_T$ is the total DOS of the unoccupied subgap DOS, and $N_{GS} = C_g(V_{GS} - V_{th})$ is the electron density induced by $V_{GS}$. The subgap DOS also determines the operation voltage of the TFT; the operation voltage is limited by the $V_{GS}$ range required to switch the TFT from the off state to the on state, which is expressed by the $S$ value defined by

$$S = \frac{dV_{GS}}{d\log I_{DS}} = \ln 10 \frac{k_B T}{e} \left(1 + \frac{e D_{sg}}{C_g}\right)$$

$D_{sg}$ is the subgap DOS at the Fermi level ($E_F$). These results indicate that reduction of the subgap DOS is the most important issue for realizing high-performance TFTs.

**The extracted procedure of parameters from Equation 1 and Equation 2:**

Equation 1:

$$I_{DS} = \frac{W}{L} \mu_{FE} C_l \left(V_{GS} - V_{th} - \frac{1}{2} V_{DS}\right) V_{DS}$$

$$I_{DS} = \frac{W}{L} \mu_{FE} C_l \left((V_{GS} - V_{th})V_{DS} - \frac{1}{2} V_{DS}^2\right)$$

The $\frac{1}{2} V_{DS}^2$ can be ignored in consideration of the very small value of $V_{DS} (~0.1V)$.

$$I_{DS} = \frac{W}{L} \mu_{FE} C_l (V_{GS} - V_{th}) V_{DS}$$

$V_{th}$ can be determined by using linear extrapolation of the tested transfer curve ($I_{DS}$-$V_{GS}$). The slope can also be obtained from linear extrapolation.

$$\text{Slope} = \mu_{FE} \frac{W}{L} C_l V_{DS}$$
\[ \mu_{FE} = \frac{L \cdot \text{Slope}}{W C_i V_{DS}} \]

Equation 2:

\[ I_{DS} = \frac{W \mu_{sat} C_i}{2L} (V_{GS} - V_{th})^2 \]

\[ \sqrt{I_{DS}} = \sqrt{\frac{W \mu_{sat} C_i}{2L}} (V_{GS} - V_{th}) \]

\( V_{th} \) can be determined by using linear extrapolation of the tested transfer curve (\( \sqrt{I_{DS}} \cdot V_{GS} \)). The slope can also be obtained from linear extrapolation.

\[ \text{Slope} = \sqrt{\frac{W \mu_{sat} C_i}{2L}} \]

\[ \mu_{sat} = \frac{2L \cdot \text{Slope}^2}{W C_i} \]

The procedure for the proposed extraction method is described as follows.

\[ \psi_s = \int_{V_{fb}}^{V_{gs}} \left( 1 - \frac{c_g(v'_{gs})}{c_{ox}} \right) dV'_{gs} \] \hspace{1cm} (1)

\[ \rho(\psi_s) = -\frac{c_g(v_{gs})}{\varepsilon_s} \frac{\nu_{fg}(v'_{gs})}{c_{ox}} \] \hspace{1cm} (2)

\[ N_t(E + q\psi_s) = -\frac{1}{q^2} \frac{\rho(\psi_s + \Delta \psi_s) - \rho(\psi_s)}{\Delta \psi_s} - \frac{n_0}{qV_s} \exp \left( \frac{\psi_s}{V_s} \right) \] \hspace{1cm} (3)

Firstly, \( \psi_s \) in terms of \( V_{gs} \) is calculated from the \( C_g - V_{gs} \) characteristics of TFTs by (1). Secondly, the surface charge concentration \( \rho(\psi_s) \) can be obtained from the \( C_g - V_{gs} \) characteristics of TFTs by (2). Finally, the density of states \( N_t(E) \) with respect to some energy level \( (E = E_{F0} + q\psi_s) \) can be extracted by (3). As seen above, the proposed extraction method of DOS has the advantages of analyticity and simplicity.