Effect of enhanced-mobility current path on the mobility of AOS TFT

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A B S T R A C T
In this study, the mobility enhancement in an Amorphous Oxide Semiconductor Thin Film Transistor (AOS TFT), particularly the effect of enhanced-mobility current path was investigated. In the TFT structure, the a-IGZO single active channel layer was replaced by double layers. Indium Tin Oxide (ITO) was employed as an enhanced-mobility current path material and was embedded in an amorphous Indium Gallium Zinc Oxide (a-IGZO) channel layer of a conventional bottom gate structure TFT. To analyze the effect of the length of an additional current path, the a-IGZO channel length was fixed at 80 μm, and the length of the ITO enhanced-mobility current path was increased to 20, 40, and 60 μm. As a result, the mobility increased monotonically with the length of the enhanced-mobility current path and was predictable from the rule of mixture. The maximum saturation mobility of 28.3 cm²/V·s resulted when the length of the enhanced-mobility current path was 60 μm. This value is more than double that of a single path TFT. Such enhancement in mobility is attributed to the high conductivity of ITO and a good conduction band match between a-IGZO and ITO.

1. Introduction

Size expandability and development of novel display devices such as transparent displays [1] is currently a major research area in display R&D. Improvement of the performance of TFT to be compatible with the next-generation display devices is a critical research goal. Among the various TFT specifications for future application, mobility is drawing great attention because it determines final device performance [2–5].

TFT mobility enhancement was initially attempted by substituting a-Si:H active layer with AOS material. Compared with the mobility of a-Si:H base TFT (0.5–1.0 cm²/V·s), the mobility of AOS TFT is high and is about 10 cm²/V·s. In addition, AOS can be used in transparent display devices because of its large optical band gap (above 3.0 eV) and can secure the transparency which a-Si:H cannot attain. Nevertheless, the mobility of AOS TFT requires further improvement [6–8].

One approach to enhance the mobility is through a highly conductive additional layer in the active layer of the bottom gate TFTs [2–4]. Kim et al. reported improvement of mobility by employing an additional layer of Mo metal thin film on the surface of the active layer. However, the mobility did not noticeably increase and the transparency decreased due to the opaque metal film [2]. In fact, the mobility is mostly influenced by the current path formed at the bottom of the active layer that is adjacent to the gate oxide in the bottom gate TFT structure. Therefore, the additional Mo layer away from the actual channel region is not much affected. Another study shows that TFT with double active layers of (Cu Ga In Zn Oxide) CGIZO and a-GIZO resulted in a field effect mobility of 11.4 cm²/V·s [3]. However, the CGIZO conductive path is still lead to an effective increase in the device mobility. In a recent study, the effect of conductive and transparent Gallium Zinc Oxide (GZO) layer was investigated [4]. The mobility increased from 6.78 cm²/V·s to 10.04 cm²/V·s when the conductive GZO of carrier concentration of 3.8 × 10¹⁸ cm⁻² was embedded at the bottom of a-IGZO active layer of carrier concentration of 5.3 × 10¹⁶ cm⁻².

In this study, we evaluated Indium Tin Oxide (ITO) material as an enhanced-mobility current path in an a-IGZO TFT. ITO is a widely used material for a transparent electrode. Not only are the material properties of ITO well known but the process technology is also well established. In particular, the ITO has a good chemical compatibility with a-IGZO due to its compositional similarity [6–12]. The work function of ITO was also considered in the selection of highly conductive materials [13,14]. An ITO thin film layer was embedded between the active layer and the gate insulator, so that it forms an enhanced-mobility current path right at the actual current path. In order to ensure the effect of the enhanced-mobility current path on the device, the mobility variation with the change in the length of enhanced-mobility current path is studied.

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2. Procedure

The bottom gate structure TFTs with an additional enhanced-mobility current path in the a-IGZO active layer were fabricated on a glass substrate.

The gate electrode of 100 nm thick Mo was deposited using DC sputtering at room temperature and patterned out using wet etching process. SiN$_x$ gate insulator deposition followed at 300°C using PECVD. A 5 nm ITO enhanced-mobility current path layer was deposited by an RF sputtering method at room temperature using an oxide single target. Then, an active layer of 50 nm thick a-IGZO was deposited using an RF power of 40 W at room temperature. During deposition, the ambient of Ar:O$_2$ in the ratio of 90:10 was maintained at 5 mTorr. Both the active layer and the enhanced-mobility current path layer were patterned using a wet etching process. In the mask design, the channel width and length was fixed at 50 $\mu$m and 80 $\mu$m, respectively. The lengths of enhanced-mobility current path layer were 20, 40, and 60 $\mu$m. The source and drain electrode of 100 nm thick Mo was deposited using DC sputtering at room temperature and patterned using the lift-off method. The device was then annealed at 300°C for an hour in an N$_2$ ambient.

The composition and structure of the TFTs were carried out by TEM analysis. Electrical characteristics were measured by current–voltage measurement using Agilent E5270B parameter analyzer.

3. Result and discussion

Fig. 1 shows a bottom-gate TFT with an enhanced-mobility current path embedded in the active a-IGZO layer. The low resistivity ITO conductive path is placed inside the a-IGZO active layer and is right on top of the Si$_3$N$_4$ gate insulator. The placement of ITO is designed by considering the actual current path. Another consideration regarding the high conductive material is a band offset with active layer material. The embedded high current path material is not supposed to form a Schottky barrier with the active layer. The injected carrier from the source electrode can be blocked by the barrier and cannot reach the drain electrode, which will lead to a low mobility. Therefore, the material for enhanced-mobility current path should be selected by carefully considering the relative energy band configuration with the active layer material. In Fig. 2, the electron affinities of the component layers are shown based on the data from the available literature. Although the band diagram shown in Fig. 2 is an ideal one and may be different from the real value, it still provides insight with regards to the contact between ITO and a-IGZO whether it shows like an Ohmic behavior or not.

Fig. 3 are the output curves of TFTs with enhanced-mobility current path lengths from 0 to 20, 40, 60 $\mu$m channel length TFTs. The channel width is 50 $\mu$m in all cases. All transistors exhibit typical output curves but different current levels in linear and saturated regions. The result also ensures that the embedded enhanced-mobility current path does not degrade the device properties. Therefore, the material combination and device structure suggested in this study can be extended to the other TFT structures.

Fig. 4 shows the transfer characteristics of transistors indicating that on-current level slightly increases as the additional path layer length increases. The mobility ($\mu_{sat}$) is determined from the following Eq. (1) [16,17] in the saturated region.

$$\mu_{sat} = \frac{2Lm^2}{Wc_{ox}}$$

where $m$ is the slope of the curve, ($I_{D, sat}$)$^{1/2}$ = ($V_{GS}$ – $V_T$), $L$ is the channel length, $W$ is the channel width, and $C_{ox}$ is the capacitance of the gate insulator for the unit area.

![Fig. 1.](image1.png)  
(a) Schematic cross section of TFT with ITO enhanced-mobility current path in a-IGZO active layer. (b) Top view of a TFT shows that the total channel length is 80 $\mu$m and the three different lengths of the enhanced-mobility current paths are 20, 40, and 60 $\mu$m.

![Fig. 2.](image2.png)  
Equilibrium band diagram of 60 $\mu$m enhanced-mobility current path TFT. No significant energy barrier was found between IGZO and ITO [13–15].
In Table 1, important device parameter from TFTs with various enhanced-mobility current path lengths are listed. The saturation mobility of TFT without an enhanced-mobility current path was measured as the reference value, and was 12.8 cm²/V s. The highest saturation mobility was found from the TFT with 60 μm enhanced-mobility current path length embedded in 80 μm channel length and resulted in 28.3 cm²/V s. Compared with the characteristics of TFT that did not have an enhanced-mobility current path, this result shows a remarkable improvement. In Fig. 5, the saturation mobility changes were drawn as a function of the length of the enhanced-mobility current path.

It was found that the saturation mobility increases with the length of the embedded current path. Therefore, it is likely that the difference in mobility shown in the above result is related to the length of the embedded current path. As described in Eq. (1), the mobility in the transistor embedded with an internal thin film reflects the mobility of both a-IGZO and ITO internal thin film. The average mobility \( (\mu_{avg}) \) can be derived from the rule of mixture where the lower bound assumes isostress state and the upper bound assumes isostrain state. In our experiment, the current path consists of series resistances of active layer (a-IGZO) and enhanced-mobility current path (ITO). This assumption is reasonable since the electrons are accumulated in the channel during the on-state. Then the average mobility is considered as an isostrain state and is summarized as follows:

\[
\mu_{avg} = \frac{\mu_a - \mu_{IGZO} \cdot \mu_{ITO}}{R_{IGZO} + \mu_{ITO} \cdot R_{ITO}}.
\]

\( R_{IGZO} \) and \( R_{ITO} \) are the length/channel length ratio of a-IGZO and ITO layer in the overall channel respectively, while \( \mu_{IGZO} \) and \( \mu_{ITO} \) are the mobilities in the respective layers. We can estimate the
average saturation mobility from Eq. (2) by plugging the mobility of a-IGZO read from Table 1 and that of ITO from the literature which are 12.8 cm²/V s and 50 cm²/V s, respectively [13]. The curve in Fig. 5 was plotted based on Eq. (2) and fits very well with the experimental values. That is, if the current path consists of two different materials with different mobility, the average mobility increases monotonically with the current path length. The increase in average mobility proven to be well matched with the rule of mixture – lower bound, which depends on the relative ratio of each component layer. Consequently, the mobility of the device increased to 28.3 cm²/V s after embedding an enhanced-mobility current layer equivalent to 75% of the entire channel length.

4. Conclusion

In this study, the structure of the bottom-gate structure TFT was modified by employing an embedded high conductive layer in order to increase the mobility. In order to maximize the efficiency, the embedded current path was placed right on top of the gate insulator where the actual channel would form. The transparent and conductive ITO was selected as the enhanced mobility current path material. ITO did not degrade the device characteristics by the reaction with the active layer during deposition or the formation of the undesirable hetero-junction barrier. This result was confirmed from the cross-sectional image analysis and deemed the cause of the typical transfer and output curves.

The enhancement of the on-current level depends on the length of the embedded current path. It was also verified that the mobility increases monotonically with the current path length. The increase in average mobility proven to be well matched with the rule of mixture – lower bound, which depends on the relative ratio of the length of the component layer. The mobility of the TFT without the enhanced-mobility current path was 12.8 cm²/V s, whereas that of 75% enhanced-mobility current path embedded in 80 μm channel resulted in 121% enhancement (28.3 cm²/V s). It is believed that such a structural modification to enhance the mobility is also applicable to other FETs.

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References