Effect of Ti/Cu Source/Drain on an Amorphous IGZO TFT Employing SiNx Passivation for Low Data-Line Resistance

Young Wook Lee, Sun-Jae Kim, Soo-Yeon Lee, Woo-Geun Lee, Kap-Soo Yoon, Jae-Woo Park, Jang-Yeon Kwon and Min-Koo Han

doi: 10.1149/2.003205esl
Effect of Ti/Cu Source/Drain on an Amorphous IGZO TFT Employing SiNx Passivation for Low Data-Line Resistance

Young Wook Lee,a Sun-Jae Kim,a Soo-Yeon Lee,a,* Woo-Geun Lee,a Kap-Soo Yoon,b Jae-Woo Park,b Jang-Yeon Kwon,c,z and Min-Koo Han,a

*a School of Electrical Engineering and Computer Science, Seoul National University, Seoul, Korea
b School of Electrical Engineering, Seoul National University, Seoul, Korea
c School of Electrical Engineering, Yonsei University, Incheon, Korea

We successfully fabricated a-IGZO TFTs with a Ti/Cu source/drain (S/D) in order to reduce the data-line resistance. SiNx passivation was used to protect the Cu from Cu-oxygen diffusion. The TFTs exhibited normal enhancement-mode characteristics compared to the TFT employing a Mo S/D, which behaved like a conductor. Our experiments suggest that the Ti/Cu S/Ds control the channel resistivity of the fabricated TFT lower than the Mo case. We found an indium-deficient IGZO layer under the Ti contact; this is thought to be the origin which reduces oxygen vacancy concentration in the channel.

Amorphous Indium-Gallium-Zinc-Oxide Thin Film Transistors (a-IGZO TFTs) have attracted a considerable amount of attention because they exhibit excellent electrical properties, such as high field-effect mobility and large on-current, along with small leakage current.1,2 Their low sub-threshold swing enables fast on/off switching; the uniformity of a-IGZO TFTs is also good.3 TFT-LCDs and AMOLEDs employing a-IGZO TFTs suggest that an oxide semiconductor is a good candidate for the switching devices used in displays.4,5

High resolutions and large display sizes require a low data-line resistivity and high mobility TFTs. When display devices increase in size, resolution, and refresh rate, the required short charging time makes it difficult to charge the pixel electrodes up to the necessary data voltage. High mobility TFTs can overcome this charging problem. However, the signal distortions due to the RC-delay of the data-line are still a liability. The RC-delay, therefore, needs to be decreased in order to avoid image distortion. Since the capacitance is usually fixed by the data-line width, the resistivity of the data-line needs to be reduced in order to decrease the RC-delay. Al is widely used for the data-line in displays, Cu, which is about 30% more conductive than Al, is being considered for data-line resistance reduction.6 Because the data line is formed simultaneously with the source/drain (S/D) electrodes, employing Cu for the oxide TFT’s S/D is very important.

A problem to employ Cu in oxide TFTs is that Cu diffuse into SiO2 passivation.7,8 so that the Cu resistance and RC-delay will increase. The reason why oxide TFTs widely use SiO2 for passivation is that it exhibits superior environmental stability.8,9 Because the data line is formed simultaneously with the source/drain (S/D) electrodes, employing Cu for the oxide TFT’s S/D is very important.

Therefore, in spite of usefulness of SiO2, when Cu-based metalization is used, it is desirable to employ SiNx passivation which is widely used in a-Si TFTs. However, there is another problem to apply SiNx passivation in the oxide TFTs, because their electrical properties are easily changed by the hydrogen species such as SiH4, NH3, and H2 during the SiNx deposition. It has been found that an oxide semiconductor TFT with SiNx passivation has negative turn-on voltage or even becomes a conductor due to the resulting increased number of carriers.

The purpose of this paper is to report upon the fabrication of a-IGZO TFTs using a Ti/Cu S/D as well as SiNx passivation. They exhibit the enhancement-mode transfer characteristics, whereas the TFT with Mo S/D and SiNx passivation does not. We investigate the Ti metallization effect on the IGZO channel, and suggest a plausible mechanism to explain the phenomena.

We fabricated the TFTs with an inverted-staggered etch-stopper structure. The gate metal (Mo) was deposited using DC sputtering on a glass substrate. After the Mo deposition, the gate was patterned by photolithography and wet-etching. 250 nm thick SiO2 was deposited by PECVD for the gate insulator. 40 nm thick IGZO (In2O3:Ga2O3:ZnO = 1:1:1 atomic%) was deposited by DC sputtering and patterned for the active layer. In order to prevent active layer damage from the post processes, i.e. S/D etching, a 50 nm thick SiO2 layer was deposited as an etch-stopper layer. We deposited a Ti/Cu bi-layer (30 nm / 300 nm) for the S/D electrodes, which was patterned by wet-etching. In order to investigate the passivation influences, we deposited two types of passivation, either a 200 nm thick SiNx or a 200 nm thick SiO2 layer. For comparison, we also fabricated TFTs employing a Mo S/D instead of a Ti/Cu S/D. After the fabrication was completed, all of the TFTs were annealed in air at 300 °C.

Figure 1 shows the transfer curves of the SiNx passivated TFTs with two different S/D metals. We can see the obvious differences in the transfer characteristics according to the S/D electrodes. In the case of the Ti/Cu electrodes, although the TFT employed SiNx passivation, it exhibited reasonable transfer characteristics, whereas the case of the Mo S/D lost its semiconductor characteristics, exhibiting conductor-like behavior. When SiO2 passivation was used, the TFTs also showed normal enhancement-mode transfer characteristics regardless of the S/D metals (not shown here).

In order to compare the IGZO resistivity of the Ti/Cu and Mo S/D, we measured the resistance of the various channel lengths with the TLM (Transfer Length Method) pattern which comprises the IGZO...
channel and the S/D without gate electrode, showed it in Fig. 2 (for the case of the SiNx passivation). The graph shows that the channel resistance of the Ti/Cu increases steeply with the channel length increasing, that means the channel resistivity could be changed according to the S/D material. Because the IGZO resistivity increases with oxygen content in itself, the result suggests there are less oxygen vacancies in the IGZO channel employing Ti/Cu S/D.

The conductor-like behavior seen in the TFT with the Mo S/D and SiNx passivation combination is attributed to the hydrogen, which is injected into the IGZO layer, increases the number of oxygen vacancies in the IGZO channel layer. Because more hydrogens are injected into the IGZO layer during the SiNx deposition compared to the SiO$_2$ deposition, the TFT with the SiNx passivation becomes like a conductor or has a negative turn-on voltage. However, our experiment employing Ti/Cu S/D exhibited excellent enhancement-mode transfer characteristics even though it was passivated with SiNx. It is clear that the same amount of hydrogen species was injected into the IGZO layer because the process conditions for the IGZO and SiNx were not changed for both Ti/Cu and Mo electrode types. Therefore, Ti/Cu S/D must be effective to reduce the oxygen vacancies generated during the SiNx passivation process, and so maintains the number of carriers in the channel sufficiently low.

Though a few papers reported that Ti metallization reduces contact resistance with oxide semiconductors, effect of S/D material on the channel layer was not reported yet. A comparison of the oxygen intensities (see Fig. 3) suggests that metal-contacted IGZO is able to influence the channel IGZO. We measured the intensity peak of each IGZO element using Energy Dispersive Spectrometry (EDS) in the IGZO layer from the channel to the contact (red bars in Fig. 3). Figure 3 shows the analyzed region and the results of the intensity measurement for both S/D metals. It is noted that the oxygen intensity near the Mo-contact is lower than that found near the Ti-contact, whereas there is little difference in the intensities of the In, Ga, and Zn. Because the oxygen intensity is inversely proportional to the oxygen vacancy (Vo) concentration, we posit that the Vo concentration of the Ti-contact IGZO is lower than that of the Mo-contact IGZO. It must be noticed that we are not able to compare the Vo concentration between the channel and the contact region because oxygen in ES layer would increase the oxygen intensity more than amount in the IGZO channel itself.

During the SiNx passivation deposition, it is evident that the Vo concentration in the channel will be increased by the hydrogen species regardless of S/D material. Such a state is schematically expressed in Fig. 4a. At the initial state after SiNx deposition, Vo concentration in the channel is larger than those of the Mo-contact and the Ti-contact IGZO, and Vo of the Mo-contact IGZO is larger than the Ti-contact IGZO as predicted through Fig. 3. Because the Vo can diffuse, the Vo concentration in the channel could be reduced by migration to the contact region. The Vo difference of the Ti/Cu S/D is greater than the case of the Mo S/D, so that reduction effect will be greater. Therefore, Vo concentration is controlled low as seen in Fig. 4b despite of the SiNx passivation.

In oxide semiconductors, the oxygen vacancies are usually considered to be electron carrier sources. Therefore, a lower Vo concentration in the IGZO channel indicates a lower carrier concentration, and that is thought to be an origin of excellent TFT characteristics despite of the SiNx passivation.

![Figure 2. TLM plot according to S/D electrode in case of the SiNx passivation.](image)

![Figure 3. The EDS profiles of the cations and the oxygen anion in the IGZO. They were scanned from the channel to the contact region, as indicated in the red eclipses. (a) the Ti/Cu S/D and (b) the Mo S/D.](image)
Figure 4. Schematic illustration which explains the VO concentration according to S/D materials: (a) Initial state, (b) After VO migration.

Referring to Fig. 5, the reason why the S/D metal influences the VO concentration in the IGZO layer can be deduced. We analyzed the contact region vertically between the Ti/Cu S/D electrode and the a-IGZO using Scanning Transmission Electron Microscopy (STEM) and EDS. Figure 5 shows the STEM image and intensity peak of each element. We studied the interfacial layer seen in the STEM image between the Ti and the IGZO layer; there is both a Ti-peak and an O-peak, as seen in the intensity graph (denoted as the II-region). This suggests that the interfacial layer contains a kind of Ti-oxides, which is similar to the result reported on the formation of Ti-oxides when oxide semiconductors make contact with Ti.13, 14, 17, 18

The notable phenomenon is the formation of the IGZO-bilayer, which is visible as the brighter region on the top of the IGZO in the STEM image. The intensity graph shows that the In-intensity varies with the depth; it is greater at the top of the IGZO, and rather small for the rest of the IGZO layer. We attribute the IGZO-bilayer to the In-rich IGZO (III) and the In-poor IGZO (IV) regions, according to the In-intensity. However, in the case of the Mo S/D, we cannot find any interface layer between the Mo and the IGZO layer.

We propose a plausible explanation for the phenomena seen in Fig. 5. When the Ti makes Ti-oxides by taking the oxygen from the contacted IGZO, the oxygen removed by the Ti might be a one bonding with indium (because Ga₂O₃ or ZnO is more stable than In₂O₃ thermodynamically). The oxygen-removed indium atoms at the contact are unstable, and such an unstable state could be relieved by bonding with the other indium atom diffused from the vicinity. This indium migration enables the formation of both the In-rich IGZO near the contact and the In-poor IGZO for the rest of the IGZO. The In-rich IGZO influences the contact characteristics, whereas the In-poor IGZO will be related to the active channel. Because VO concentration is decided by the ratio of metal cation (especially, In) and oxygen anion, there are less oxygen vacancies in the In-poor IGZO. That makes VO concentration difference between in Mo-contact IGZO and Ti-contact IGZO, as presumed through Fig. 3.

In conclusion, we investigated a Ti/Cu structure for the S/D electrode in order to reduce the data-line resistance. When SiNx passivation was employed, the a-IGZO TFT with the Ti/Cu S/D exhibited excellent transfer characteristics whereas the Mo S/D case showed conductor-like behavior. Our experiments suggest that Ti/Cu S/D can control the channel’s VO concentration. We proposed a plausible mechanism and supporting analysis which are able to explain Ti-metallization effect on VO concentration in the both the channel and the contact region.

References