Contact Properties between Low-Resistive Al-Based Source/Drain and InO_x in Top-Gate Bottom-Contact Oxide Thin-Film Transistor for Application to the Vertical-TFT

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ABSTRACT

Vertical-TFT is a promising structure to realize ultra-high resolution displays. Especially, low-resistive Al-based source/drain is necessary to reduce RC delay. Since vertical-TFT is bottom-contact structure, source/drain is oxidized during InO_x semiconductor deposition. Here, we present the quantitative analysis result of metal/active contact properties in top-gate bottom-contact structured TFT, mimicking vertical-TFT.

1 INTRODUCTION

For high resolution realization, oxide thin-film transistor (TFT), which has been extensively studied because of its characteristics of good uniformity, high mobility, and low off current [1]. Recently, display is evolving to ultra-high resolution to achieve virtual reality (VR) and augmented reality (AR). To obtain ultra-high resolution displays with more than 3000 pixels per inch (PPI), pixel size needs to be smaller. Among the TFT structure, vertical-TFT (V-TFT) shown in Fig. 1, which has the smallest pixel pitch value, is a rising candidate for next generation displays [2, 3]. Furthermore, using the Al electrode is also very important to reduce RC delay in the high resolution pixel array.

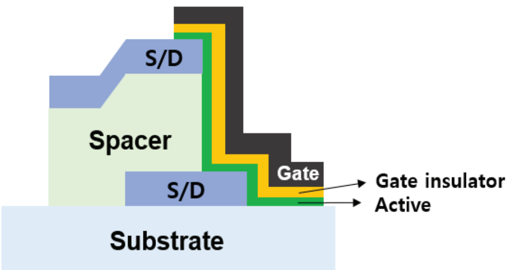

Fig. 1. Cross section view of V-TFT

However, there is a structural limitation in using low resistive Al-based electrodes, since V-TFT has the bottom-contact structure where the oxide semiconductor is deposited on the source/drain (S/D) electrode under oxidation environment. This deposition process leads to inevitable oxidation of Al, causing the contact issue. While the relation between metal/semiconductor interface and TFT performance in top-contact structure (e.g. BCE) has been studied [4], research on the contact issues in bottom-contact structured TFT is rare.

In this study, we have analyzed the electrical performance of TFTs with different Al-based S/D and contact properties between oxide semiconductor and S/D electrode in top-gate bottom-contact (TGBC) structured oxide TFT. Since these TGBC can mimic the contact in V-TFT, we could suggest the proper process solution to minimize the contact resistance in V-TFT.

2 EXPERIMENT

All TFTs were fabricated at lower than 200°C to prevent Al metal oxidation and we adopted the S/D protecting layer like Mo or Ti. As the first step of this research, we fabricated TGBC TFTs shown in Fig. 2 with Mo gate and three types of S/D electrodes; Mo/Al/Mo, Ti/Al/Ti, and ITO. InO_x active and Al_2O_3 gate insulator layers were deposited by plasma-enhanced atomic layer deposition (PEALD) method. Additionally, post-annealed treatment was carried out at 200°C under vacuum condition. The electrical properties of TFTs were analyzed with transfer (I_{DS}-V_{GS}) curves by HP 4156A. The electrical parameters of mobility were calculated from those curves.

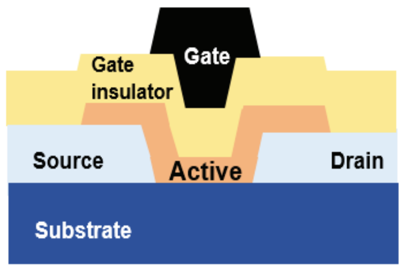

Fig. 2. Cross section view of TGBC TFT

The transmission line method (TLM) was adopted for analyzing contact resistance [5]. As shown in Fig. 3, the on-state resistance (R_{on}) values were extracted from the I_{DS}-V_{GS} curves in the linear region at gate voltage (V_{GS}) = 1, 3, and 5V by using the Eq. (1):

$$R_{on} = \frac{V_{DS}}{I_{DS}} = \frac{R_S}{W}(L - 2\Delta L) + 2R_{SD}. \quad (1)$$

R_S, R_{SD}, L, and ΔL mean sheet resistance, contact resistance, channel length, and error in the channel length, respectively. To support the derived contact values, the interface between InO_x active layer and S/D was analyzed by x-ray photoelectron spectroscopy (XPS) depth profile analysis.

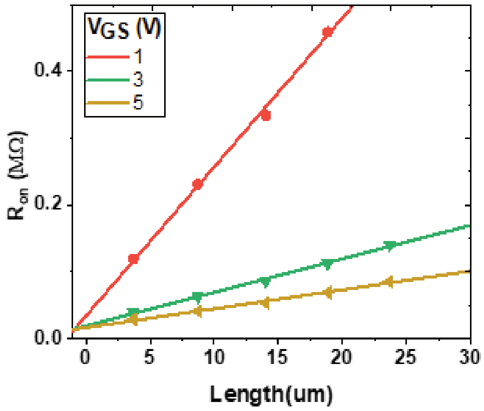

Fig. 3. R_{on} – L plot extracted from the I_{DS}-V_{GS} curves at V_{GS} =1, 3, and 5V

3 RESULTS AND DISCUSSION

3.1 Transfer properties of Al-based S/D TGBC TFTs

Fig. 4 shows transfer curves of (a) as-fabricated and (b) 200°C vacuum annealed InO_x TGBC TFTs with Mo/Al/Mo, Ti/Al/Ti, and ITO S/D with channel width and length of 20 and 5 μm. The applied drain voltage (V_{DS}) is 0.1V. Since ITO is the non-metal electrode, the transfer characteristics are little degraded as shown in Fig. 4-(a), exhibiting mobility of 27.71 cm^2/V-s. However, as-fabricated Mo/Al/Mo and Ti/Al/Ti S/D TGBC TFTs exhibit lower current level and mobility of 8.39 and 3.16 cm^2/V-s, respectively. In particular, Ti/Al/Ti S/D TGBC shows more deteriorated electrical properties than Mo/Al/Mo S/D TGBC. After 200°C vacuum annealing process, the mobility of TFT with Mo/Al/Mo S/D is improved to 26.99 cm^2/V-s, which is similar to that of ITO S/D (30.49 cm^2/V-s). Although Ti/Al/Ti S/D TGBC also shows improved mobility of 12.09 cm^2/V-s after heat treatment, it has been confirmed that Ti/Al/Ti S/D TGBC has more degraded properties than Mo/Al/Mo S/D TGBC.

3.2 Contact properties of Al-based TGBC TFTs

Fig. 5 shows R_{SD} values of the Mo/Al/Mo, Ti/Al/Ti, and ITO S/D TGBC TFTs. Before the annealing process, Ti/Al/Ti S/D has the highest R_{SD} among the three types of electrodes. Mo/Al/Mo S/D has higher R_{SD} than ITO S/D but much lower R_{SD} than Ti/Al/Ti S/D. After annealing process at 200°C, the R_{SD} values of Mo/Al/Mo, Ti/Al/Ti, and ITO S/D TFTs are reduced, showing values of 2332, 6716, and 46Ω, respectively. The difference in R_{SD} among the TFTs is greatly reduced. Although it can be assumed that the surfaces of Al-based metal S/D are affected during the deposition of the active layer in bottom-contact TFTs, contact problems can be alleviated by the proper annealing process. Nevertheless, it is confirmed that the contact issue of the Ti/Al/Ti S/D TGBC still exists in bottom-contact structured TFT.

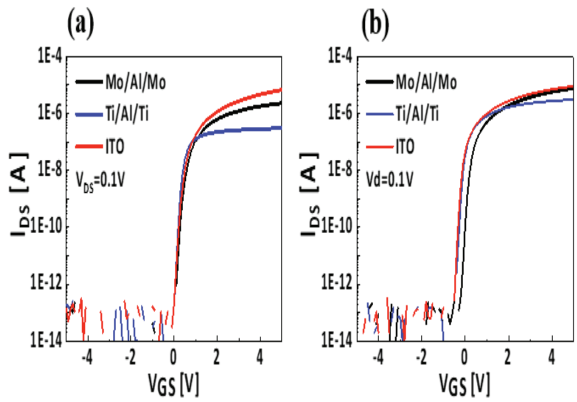

Fig. 4. Transfer characteristics of (a) as-fabricated and (b) 200°C vacuum annealed Mo/Al/Mo, Ti/Al/Ti, and ITO S/D TGBC TFTs with channel width/length of 20/5μm

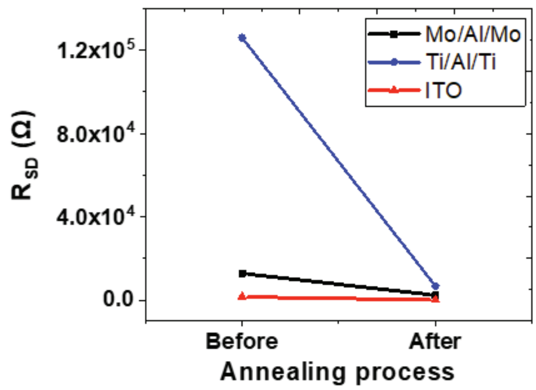

Fig. 5. Contact resistance values of Mo/Al/Mo, Ti/Al/Ti, and ITO S/D TGBC TFTs before and after annealing treatment calculated by TLM

3.3 XPS analysis of contact interface

XPS depth profile method was conducted to analyze the interface between InO_x active layer and S/D metal. Fig. 6 shows data on the metal peaks of (a) Mo 3d, (b) Ti 3d, and (c) Al 2p, showing S/D metal bulk region (black line) and contact region (blue line). Red dotted lines represent the binding energy of each metal oxide. The pick of Ti 3d metal at the binding energy around 452.5eV in the contact region (blue line) is the In metal signal. As shown in Fig. 6-(a), it is confirmed that little MoO_2 layer is formed. However, in the case of Ti and Al, it can be seen that TiO_2 and Al_2O_3 are formed as shown in Fig. 6-(b) and (c). These results mean that the oxidation of the metal electrode occurs during the active deposition process, and the degree of oxidation depends on the

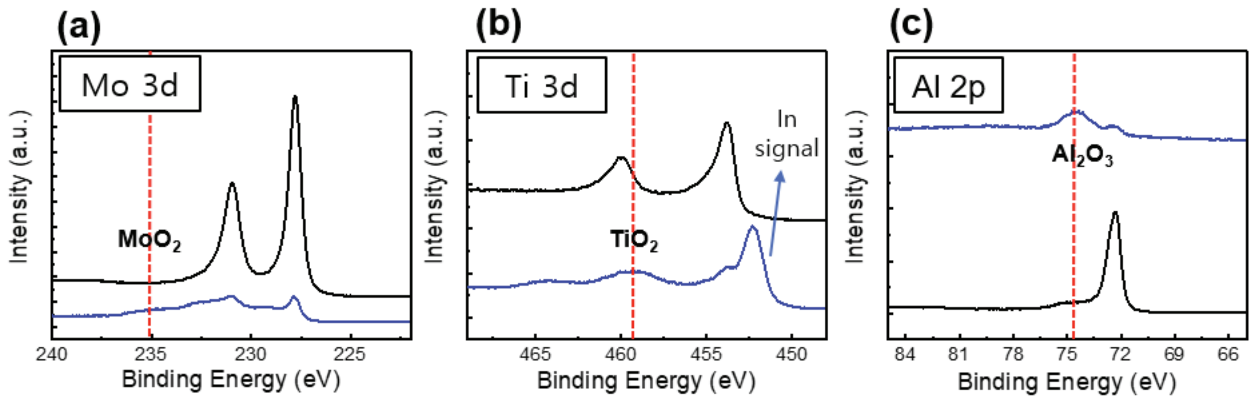

Fig. 6. Metal peak of (a) Mo 3d, (b) Ti 3d, and (c) Al 2p, showing S/D metal bulk region (black line), contact region (blue line), and binding energy of metal oxide region (red dotted line)

type of metal, as expected from the reaction Gibbs free energy ($\triangle G_{rxn}$). The formation of TiO_2 and Al_2O_3 is more stable than Ti and Al metal states because $\triangle G_{rxn}$ values in which InO_x and Ti or Al react to form TiO_2 or Al_2O_3 is negative. As a result, high resistance TiO_2 and Al_2O_3 layers act as barriers to carrier injection, and affect R_{SD}. On the other hand, Mo is more stable than MoO_2 formation in the contact region [6]. Therefore, it has been verified that the Ti/Al/Ti S/D TGBC has higher contact resistance and deteriorated properties than Mo/Al/Mo S/D TGBC.

Since the oxide active layer is deposited on the S/D in the bottom-contact structure (e.g. TGBC and V-TFT), Al oxidation is unavoidable but the choice of protecting metal layer (e.g. Mo or Ti) can affect contact and electrical properties of TFT. Analyzing the contact resistance and electrical performances of TFT in the bottom-contact structure with Al-based S/D contributes to the development of V-TFT with reduced RC delay for ultra-high resolution displays.

4 CONCLUSIONS

A study of TGBC structure can mimic the contact between the S/D and oxide semiconductor of V-TFT, which is assumed as the best TFT structure for the ultra-high resolution displays. We report electrical performances and contact properties of InO_x TGBC TFTs with Al-based S/D. TFT with Ti/Al/Ti S/D shows higher contact resistance with InO_x than that of Mo/Al/Mo S/D, resulting in lower current level and mobility. From the results of XPS depth profile analysis, we have confirmed the formation of Al_2O_3 and TiO_2. Therefore, Al-based metal S/D electrodes are oxidized during the deposition of the active layer. However, the selection of protecting metal layer (e.g. Mo or Ti) can improve the electrical and contact properties in bottom-contact structured oxide TFT.

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REFERENCES

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, "Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors", *Nature*, Vol. 432, No. 4016, pp. 488-492 (2004).

[2] H. I. Yeom, G. Moon, Y. Nam, J. B. Ko, S. H. Lee, J. Choe, J. H. Choi, C. S. Hwang, and S. H. Ko Park, "Oxide vertical TFTs for the application to the ultra-high resolution display", *SID symposium Dig.*, Vol. 60, No. 3, pp. 820-822 (2016).

[3] C. S. Hwang, S. H. Ko Park, H. Oh, M. K. Ryu, K. I, Cho, and S. M. Yoon, "Vertical channel ZnO thin-film transistors using an atomic layer deposition method", *IEEE Electron Device Lett.*, Vol. 35, No. 3, pp. 360-362 (2014).

[4] Y. Shimura, K. Nomura, H. Yanagi, T. Kamiya, M. Hirano, and H. Hosono, "Specific contact resistance between amorphous oxide semiconductor In-Ga-Zn-O and metallic electrodes", *Thin Solid Films*, Vol. 516, No. 17, pp. 5899-5902 (2008).

[5] Y. Ueoka, Y. Ishikawa, J. P. Bermundo, H. Yamazaki, S. Urakawa, Y. Osada, M. Horita, and Y. Uraoka, "Effect of contact material on amorphous InGaZnO thin-film transistor characteristics", *J. J. Appl. Phys.,* Vol. 53, No. 3S1, p. 03CC04 (2014).

[6] S. Lee, H. Park, and D. C. Paine, "A study of the specific contact resistance and channel resistivity of amorphous IZO thin-film transistors with IZO source-drain metallization", *J. Appl. Phys.*, Vol. 109, No. 6, p. 063702 (2011).