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High-Mobility a-IGZO Thin-Film Transistor Using Ta_2O_5 Gate Dielectric

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1. Introduction

Recently, studies on transparent oxide thin-film transistors (TFTs) have attracted considerable attention with respect to display applications because of the high mobility and high aspect ratio of these transistors. Nomura *et al.* [1] reported the fabrication of a transparent TFT using amorphous indium gallium zinc oxide (a-IGZO) as the channel layer and a high-k gate dielectric. The low dielectric constant leads to a poor gate control over the driving current, resulting in a poor subthreshold swing (SS), high threshold voltage (V_T), and high operating voltage of the a-Si:H TFTs. A probable approach to solving these problems and realizing high-performance a-IGZO TFTs is to enhance the gate capacitances of the TFTs. Therefore, it is preferable to introduce gate dielectric materials with a high k value. The Ta_2O_5 thin film belongs to the category of high-value oxide films [2–5] that have good chemical stability, low optical loss, and a high refractive index; these films have found applications in optoelectronic devices [6].

In this paper, we have reported the fabrication of a high-performance a-IGZO TFT with a 200-nm Ta2O5 layer as the gate dielectric. The high-performance a-IGZO TFT device has a high mobility as well as a low operating voltage and a small subthreshold swing. This a-IGZO TFT also allows a low-voltage operation with a low power expense for display applications.

2. Experimental

Aluminum that formed the gate electrode was deposited through a shadow mask using a thermal evaporation process on a glass substrate. The 200-nm Ta_2O_5 gate dielectric was deposited by e-beam at room temperature. The deposition conditions for the Ta_2O_5 dielectric were as follows: the O_2 flow rate was 20 sccm, and the deposition rate was 0.5 A/s. The 50-nm a-IGZO active layer was then deposited by RF sputtering through another shadow mask. During the sputtering, the rf power, chamber pressure, O_2 flow rate, and Ar flow rate were maintained at 112 W, 20 mTorr, 2 sccm, and 61 sccm, respectively. Finally, we thermally evaporated an Au layer onto the a-IGZO film through the third shadow mask to serve as the source and the drain electrodes. The gate length (i.e., L) and the gate width (i.e., W) of the fabricated a-IGZO TFTs were 200 and 2000 μm, respectively. These devices were characterized by current–voltage (I–V) and capacitance–voltage (C–V) measurements using a B1500 semiconductor parameter analyzer and an HP4284A precision LCR meter, respectively.

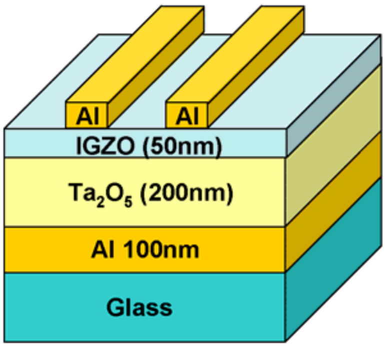

Fig. 1 Schematic representation of a-IGZO TFT with Ta_2O_5 gate dielectric.

3. Results and Discussion

Fig. 1 shows the schematic representation of a cross section of an a-IGZO TFT, where the bottom-gate device structure is used.The output I_D–V_D characteristics of the a-IGZO TFT are shown in Fig. 2 It can be seen that the device showed typical transistor characteristics with clear pinch-off and current saturation. Fig. 3 shows the transfer I_D–V_G characteristics of the a-IGZO TFT. The values of μ_{FE} and V_T were determined from the linear $I_D^{1/2}$ versus V_G plot. The apparent field-effect mobility induced by the transconductance at a low drain voltage V_{DS} = 1 V was determined by

$$\mu_{FE} = \frac{Lg_m}{WC_iV_{DS}}$$

where C_i and gm are the gate capacitance per unit area and the transconductance, respectively [7]. Once we had the values of W, L, gm, and Ci, we could calculate the values of the field-effect mobility. In our device, we obtained a high field-effect mobility of 61.5 cm^2/Vs, threshold voltage of 0.25 V, and subthreshold gate voltage swing (SS) of 0.61 V/decade. The field-effect mobility obtained was comparable to that of high-mobility a-IGZO reported thus far.

The C–V characteristics of $Al/Ta_2O_5/P^+$-Si/Al are shown in Fig. 4. The measured high capacitance density of 62 PF/cm2 resulted in an equivalent oxide thickness of 200 nm and a k value of 29.5 in the Ta_2O_5 dielectric. Fig. 5(a) shows the AFM image of the Ta_2O_5 gate insulator. It indicates that the rms of the Ta_2O_5 film was only 1.802 nm. Fig. 5(b) shows the AFM image of the IGZO film deposited on the used Ta_2O_5 film; it indicates that the RMS of the IGZO film was 2.9 nm. The smooth insulator surface played a very important role in our high-performance device.

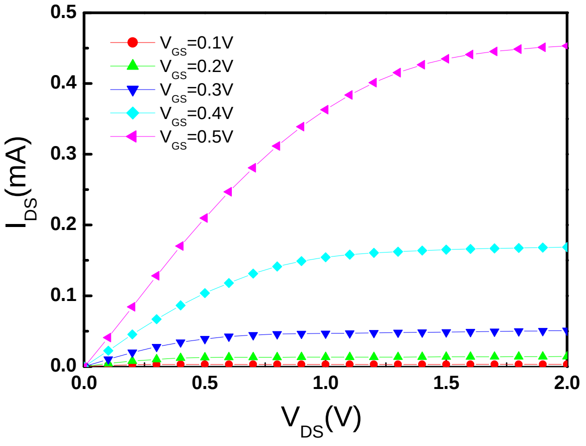

Fig. 2 Output characteristics of a-IGZO TFT with Ta_2O_5 gate dielectric.

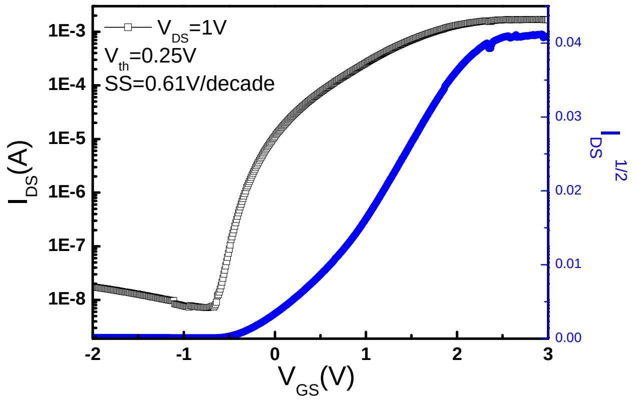

Fig. 3 Transfer characteristics of a-IGZO TFT using Ta_2O_5 gate dielectric.

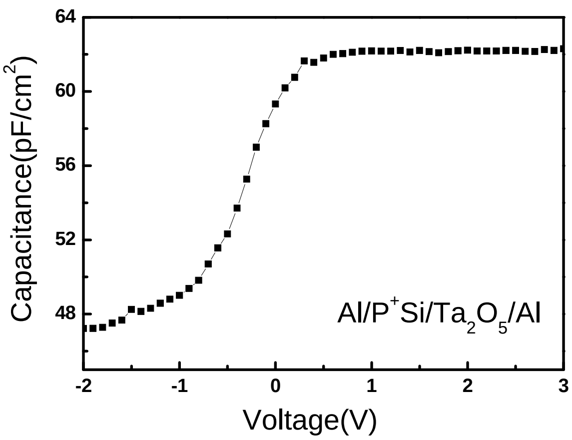

Fig. 4 C–V characteristics of Al/Ta_2O_5/P$^+$Si/Al capacitor.

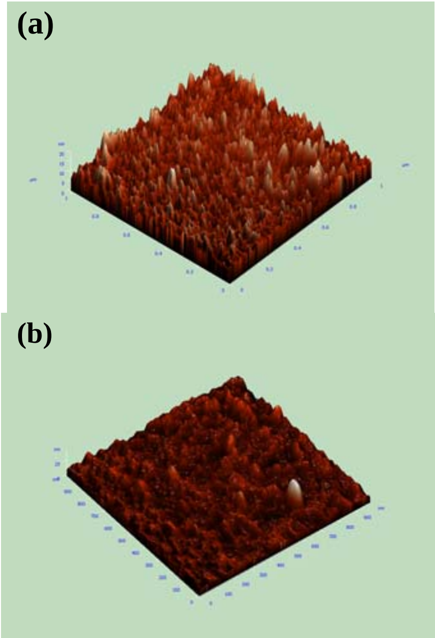

Fig. 5 (a) AFM images of 200-nm Ta_2O_5 insulator and (b) AFM images of IGZO film deposited on Ta_2O_5 film. (Scan area: 1 μ × 1 μ).

3. Conclusions

In summary, we fabricate an amorphous indium gallium zinc oxide (a-IGZO) thin film transistor with a Ta_2O_5 dielectric on a glass substrate. The room-temperature-deposited a-IGZO channel with Ta_2O_5 exhibits the following operating characteristics: threshold voltage of 0.25 V, drain-source current on/off ratio of 10^5, subthreshold voltage of 0.61 V/decade, and field-effect mobility of 61.5 cm^2/Vs.

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