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Metal-oxide thin film transistors with co-sputtering novel aluminum zinc oxide yttrium channel layer

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Introduction

Recently, metal oxide-based thin film transistors (TFTs) have attracted much attention because they have shown good electrical performance and can be manufactured at low temperatures to produce large-area displays with low cost. Metal oxide-based TFTs using Zn-O,[1] In-Zn-O,[2] In-Ge-Zn-O[3,4] as an active channel have been widely studied. The important feature of these oxide channel materials is that they are multi-component and thus they have a large flexibility to tune the TFT-related properties. Due to the advantages of inexpensiveness, low electrical resistivity, high mobility and optical transparency in the visible region, aluminum zinc oxide (AZO) materials are investigated as transparent conductive oxide (TCO). But a few works of AZO material system are reported as a semiconductor layer for metal-oxide TFTs. In this report, we discuss the characteristics of novel aluminum zinc oxide yttrium (AZOY) channel-modulated component by r.f. co-sputtering for metal-oxide TFTs for this purpose.

Experimental

The heavily doped p-type silicon wafer with 0.3 μm thick thermal oxide was chosen as the gate electrode and dielectric, respectively. The ZnO-doped AZOY active layer was deposited by co-sputtering of an AZOY target and a zinc oxide (ZnO) target with the RF power of 30 and 50 W, respectively. The channel thickness of the ZnO-doped AZOY films was typically 45 nm. The sputtering process was performed by introducing the oxygen gas at a substrate temperature of 125 ℃ with a chamber pressure of 5 × 10^{-3} torr. Then, the 90 nm thick indium zinc oxide (IZO) film was sputtered as source and drain electrodes onto the AZOY channel through a shadow mask. Fig. 1 shows the schematic structure of the top contact/bottom gate AZOY-based TFT. The channel width and length were W = 2 mm and a variation of L = 100-250 μm, respectively. The current-voltage (I-V) characteristics of the devices were measured by HP 4156A and Keithley 4200 semiconductor parameter analyzer in the dark at room temperature.

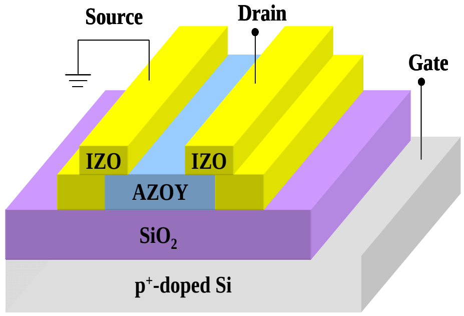


Fig. 1 A schematic structure of the top contact/bottom gate TFTs.

Results and discussions

The transfer characteristics of the AZOY-based TFTs (L = 200 μm) deposited at room temperature and by introducing the oxygen gas (0.2 sccm or 0.2 cubic centimeter per minute at STP) into chamber at 125 ℃ substrate temperature are shown in Fig. 2. The TFTs without heating the substrate exhibits a saturation mobility (μ) of 0.024 cm^2/V-s, a threshold voltage (V_T) of -27.61 V, a on/off current ratio (I_{on}/I_{off}) of 34.24, and a subthreshold swing (S.S.) of 42.70 V/decade at the V_{DS} of 50 V. However, the performance of TFTs with heating the substrate in the O_2 atmosphere is sufficiently improved, which shows a mobility of 0.065 cm^2/V-s, V_T of 3.09 V, the I_{on}/I_{off} of 56.89, and S.S. of 34.21 V/decade at V_{DS} = 50 V. The field-effect mobility (μ) in the saturation region is evaluated from the following equation under the condition of $V_{DS} > V_G - V_T$,

$$I_{DS(sat)} = \frac{W}{2L}\mu C_i (V_G - V_T)^2 \qquad (1),$$

where W and L are the width and length of the channel, respectively. C_i is the gate dielectric capacitance per unit area.

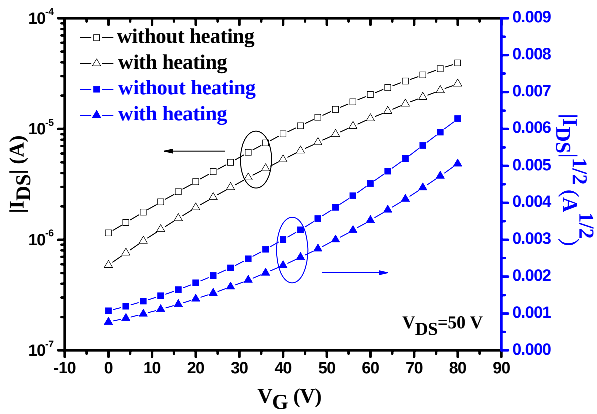


Fig. 2 The transfer characteristics of the AZOY-based TFTs without and with heating the substrate.

Figs. 3(a) and 3(b) show the transfer characteristics of the TFTs (L = 200 μm) with the active layers deposited by flowing oxygen gas at the 125-℃ substrate temperature. The oxygen flow rate were changed from 0.2 to 0.8 sccm. The saturation mobility of TFTs decreases from 0.065 to 0.033 cm^2/V-s, and the threshold voltage enhanced from 3.09 to 35.03 V. The mobility decreases with increasing the oxygen flow rate, which is supposed to be originated from the decrease of carrier concentration. It is suggested to the annihilation of oxygen vacancies in the material structure.[5] The performance of TFTs would be slightly degraded for the AZOY channel layer deposited by increasing the oxygen flow rate. However, the on/off current ratio is greatly improved to 10^4, as shown in Fig. 3.

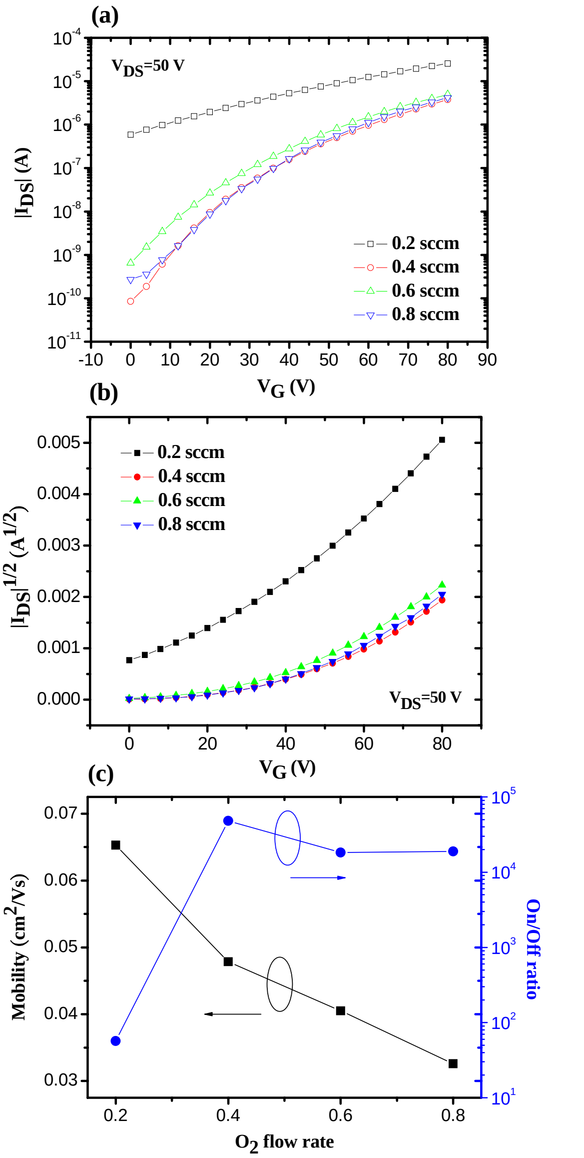
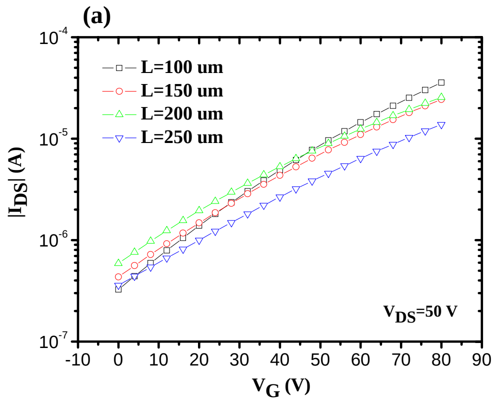


Fig. 3 The transfer characteristics of (a) $|I_{DS}|$ vs. V_G, (b) $|I_{DS}|^{1/2}$ vs. V_G for the TFTs (L = 200 μm) with the active layers deposited by introducing the oxygen gas (0.2-0.8 sccm) at 125-℃ substrate temperature, (c) the saturation mobility and on/off ratio as a function of O_2 flow rate.

Figs. 4(a) and 4(b) present the drain current as a function of gate voltage for the TFTs with various channel lengths. The active layers were deposited by introducing the oxygen gas (0.2 sccm) with the heating substrates. Fig. 4(c) shows that the field-effect mobility of TFTs increases from 0.065 to 0.13 cm^2/V-s as the channel length decreases from 250 to 100 μm.



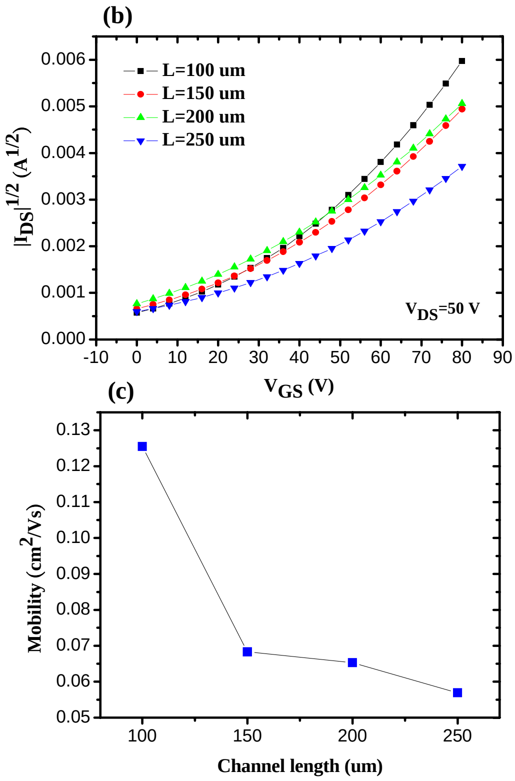


Fig. 4 The transfer characteristics of (a) $|I_{DS}|$ vs. V_G, (b) $|I_{DS}|^{1/2}$ vs. V_G for the TFTs (L = 100-250 μm) with the active layers deposited by introducing the oxygen gas (0.2 sccm) at 125-℃ substrate temperature, (c) The saturation mobility as a function of channel length.

The grain boundaries or traps would arise with increasing the channel length of TFTs. The electrons have more probability to scatter at the grain boundaries or are trapped by the interface states for long-channel, and thus degrade the device performance; that is, the mobility of long-channel devices is lower than that in short-channel devices. The AZOY-based TFTs (L = 100 μm) exhibit a saturation mobility of 0.13 cm^2/V-s, a threshold voltage of 30.31 V, a on/off current ratio of 1.50 × 10^2, and a S.S. of 29.34 V/decade at V_{DS} = 50 V .

Conclusions

In summary, we have successfully manufactured the top contact/bottom gate TFTs with the novel AZOY material channel. The ZnO-doped AZOY-channel TFTs fabricated by r.f. co-sputtering show the improved characteristics of the n-channel transistors. The saturation mobility and on/off current ratio of metal-oxide TFTs can be improved by introducing oxygen gas into chamber with heating the substrate during depositing.

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