Enhancement of Field Effect Mobility of RF-sputtered In_2O_3 Thin Film Transistor by Titanium Floating Metal

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ABSTRACT

We demonstrate In_2O_3 thin film transistors fabricated by RF-magnetron sputtering. The additionally deposited floating metal enhanced the field-effect mobility. TCAD simulation showed current bypassing through the metal layer. Furthermore, potential change might occur at the interface.

1 Introduction

Indium-gallium-zinc-oxide (IGZO) has gathered tremendous interest for next generation flat-panel display applications[1]. At the same time, various oxide semiconductors have been studied in addition to IGZO for further performance. For example, In_2O_3 TFT has much higher mobility than IGZO, which is preferable for high speed displays. However, However, it is difficult to control the electric field in the active layer due to its too high carrier concentration and uniformity due to poly-crystallization.

In recent studies, the amorphous In2O3 film has been successfully deposited by the atomic layer deposition (ALD), whose thickness is thinner (<2 nm) than IGZO's [2]. However, unlike CMOS-based industries, ALD equipment can be a big challenge because the display industry needs more than 100 inches of chambers for manufacturing. Therefore, establishing a process with RF magnetron sputter, widely adopted in the display industries, should be carried out. On the one hand, according to previous studies, there have been reports of improving mobility by depositing metal materials on the active channel layer with floating metal[3]. They explained that the change in the band structure of the interface due to the work function of the deposited metal material contributes to mobility improvement.

In this paper, an ultra-thin In_2O_3 film transistor is demonstrated by using RF magnetron sputtering, and a mobility enhancement is achieved by depositing floating metal on the In_2O_3 channel layer. To figure out the physical transport mechanism in ultrathin In_2O_3 TFT, we systematically analyzed the thickness dependence on In_2O_3 deposited by RF sputtering and the changes in the band structure according to the presence of floating metal.

2 Experimental methods

In2O3 thin films are grown through RF magnetron sputtering on 200 nm-thermally oxidized heavy doped p-type silicon. The Argon flow rate is 30 sccm and sputtering pressure was maintained 6 mTorr. The thickness of In_2O_3 is varied (1.0 / 1.2 / 1.4 / 1.6 / 1.8 / 2.0 nm) under same RF power of 50 W. A lift off method is used for electrical isolation between devices, and titanium 50 nm is deposited using RF sputtering through the photolithography and lift off method to form a source and drain. The width (W) is 400 μm, and the lengths (L) are 10 to 40 μm. In the case of floating metal, it is patterned and deposited simultaneously with the source/drain metal. The completed samples are annealed in an ambient air atmosphere with a 150 ºC hot plate for 1 hour for dehydration.

A schematic illustration of device is shown in Fig. 1a and device with floating metal is shown in Fig. 1b.

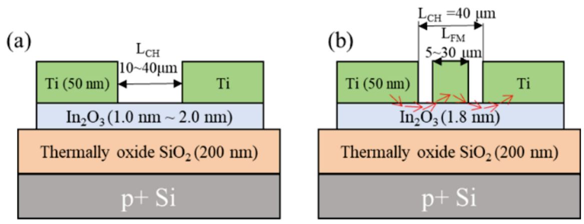

Fig. 1 The cross-section of (a) In_2O_3 TFT device with various channel lengths (L_{CH}) and (b) In_2O_3 TFT with additional floating metal, whose length (L_{FM}) varies from 10 μm to 40 μm.

3 Results and discussions

3.1 In_2O_3 active layer thickness dependence of electrical properties on thin film transistors

Fig. 2 shows the layer thickness dependence on the TFT characteristic of In_2O_3 TFT when drain voltage (V_{DS}) is 10.1 V and W and L are 400 and 40 μm, respectively. In the previous report [4], depletion mode TFT characteristics were observed with a thickness of 0.7 nm. However, in our work, when the thickness of In2O3 is thicker than 1.2 nm, the device shows switching characteristics with the on-off ratio increase. It might be because the sputtering process has inferiority in terms of surface roughness or uniformity. At a thickness of 2 nm, the on-off ratio decreases with high conductivity. We assume that -40 V was insufficient to deplete the active layer due to a high carrier concentration.

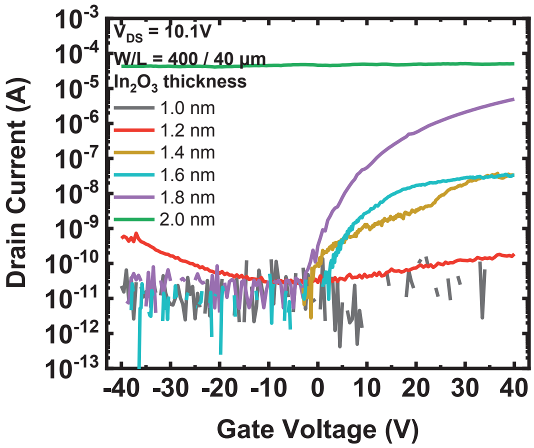

Fig. 2 In_2O_3 TFT characteristics with varied thickness of active channel.

3.2 Floating metal length dependence of TFT characteristics on In_2O_3 TFT

To increase the mobility of In_2O_3 TFTs, we created an additional Ti floating metal on the active layer between the source and drain. Fig. 3 shows transfer curves with varying lengths of the floating gate. The on-current level increases as the floating metal length (L_{FM}) increases.

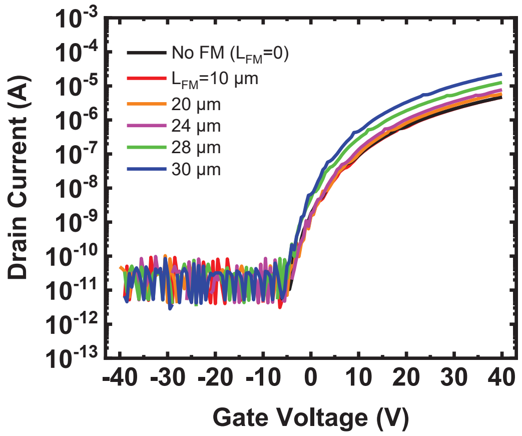

Fig. 3 In_2O_3 TFT characteristics with additional floating metal on surface of the In_2O_3 active layer. Each colors denote various length of Ti floating metal.

We assumed that the possible effects of the floating metal between source and drain are assisting the active layer as an additional current path and with a potential change. As illustrated in Fig. 1b, when the Ti layer contacts the In_2O_3 active layer directly, electrons in the active layer can flow through the metal. In this case, there will be an effect of channel length decrease. To verify our assumption, we performed the TCAD simulation and analyzed the TFT characteristics having various channel lengths

3.3 TCAD simulations of TFT with floating metal and length dependence of floating metal

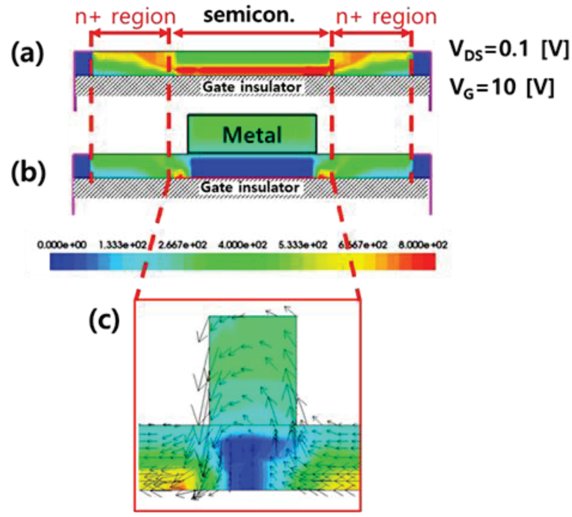

Fig. 4 Calculated current density by using TCAD simulation.

Fig. 4 is TCAD simulation results of current density when gate voltage (V_G) and drain voltage (V_{DS}) are set to 10V and -0.1V, respectively. As shown in Fig. 4(a), in standard TFT (without a floating metal), current mainly flows through the interface between oxide semiconductor and gate insulator. However, in TFT with floating metal, current flows along bulk side of semiconductor and floating metal (Fig. 4b). Fig. 4c shows how current vector changes when the current passes through the floating metal from oxide semiconductor. Here, we can assume that effective channel length is shortened ($L = L_{CH} – L_{FM}$) because the semiconductor underneath the floating metal no longer acts as a current path, and the current path is replaced by the floating metal.

Fig. 5 shows the channel length dependence of In_2O_3 TFT. When the channel length becomes shorter, the current level increases as we expected, which coincides with the TCAD simulation. To compare transport characteristics between effective length in floating metal deposited devices and channel length varied device, we plotted field effect mobility along channel length on Fig. 6a. In this case, we assumed L of TFT with floating metal as 40 μm fixed for calculation of field effect mobility. On the other hands in Fig. 6b, field effect mobility calculated with effective channel length ($L = L_{CH} – L_{FM}$ (μm)).

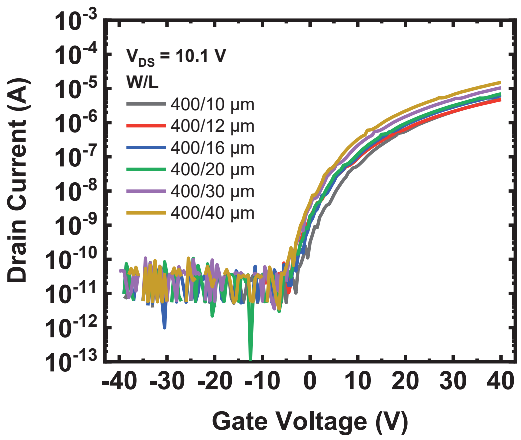

Fig. 5 In2O3 TFT characteristics with varied channel length.

The field effect mobility which is calculated by using effective channel length ($L = L_{CH}$ L_{FM}) shows a mobility well-matched tendency with the mobility of standard TFT with various channel length (Fig.6b).

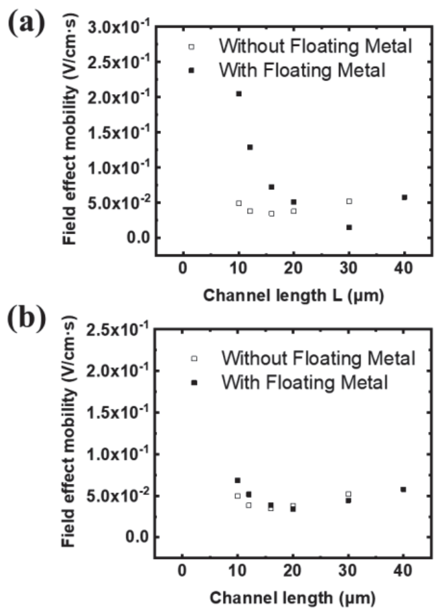

Fig. 6 Field effect mobility according to the channel length when (a) it is calculated with L_{CH}= 40 μm and (b) with 40 – L_{FM} μm.

However, as the length of the floating metal increases, the mobility increases slightly as the covering part of the active surface increases, which is believed to be because the conduction band of In_2O_3 at the interface bends due to its work function difference [3] when it forms interface while the metal which forms interface with vacuum does not, as illustrated in Fig. 7.

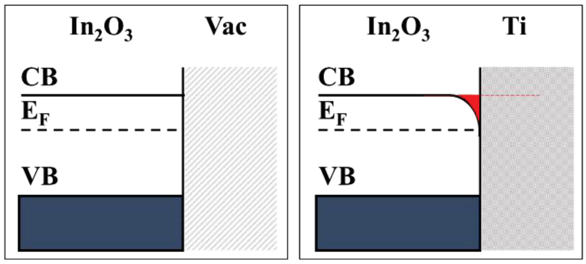

Fig. 7 Band illustration when In_2O_3 forms interface with vacuum (left) and Titanium (right).

4 Conclusions

We demonstrated the TFT properties of In_2O_3 TFT with and TFT with floating metal. Additional floating metal increases on-current level due to current bypassing and interfacial band manipulation. The fact that the current can flow to the floating metal was confirmed using TCAD simulation, which compared to the physical TFT length reduced by the length of the floating metal, which corresponds to the distance between the source trains. In addition, as the length of the floating metal is increased, an abnormal mobility that cannot be explained by bypassing the current is observed, and this is because the degree of bending at the interface between titanium and In_2O_3 is greater than that at the bending of the conduction band occurring at the interface between vacuum and In_2O_3. In addition, it is judged that the interface of In_2O_3 can be better understood through experiments to introduce a wider area of floating metal or change the type of floating metal.

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