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High-Performance Thin-Film Transistors with ZnO/Al_2O_3 Superlattice Channel Fabricated by Atomic Layer Deposition

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Abstract

High-performance thin-film transistors (TFTs) with ZnO/Al_2O_3 superlattice channel were successfully fabricated by atomic layer deposition (ALD). The morphological and electrical properties of the TFTs with ZnO/Al_2O_3 superlattice channel were studied. The TFTs with $ZnO/Al_2O_3/ZnO$ structure exhibited optimum performance with low threshold voltage (V_{TH}) of 0.9V, high mobility (μ_{sat}) of $109 cm^2V^{-1}s^{-1}$, steep subthreshold swing (SS) of 162mV/decade and high I_{on}/I_{off} ratio of 3.15×10^8. The enhanced electrical properties were explained on the improved crystalline nature of the channel layer and passivation effect of Al_2O_3 layer.

1. Introduction

Recently, thin-film transistors (TFTs) using an oxide semiconductor as an active layer, such as Zn-O, In-Ga-Zn-O, Al-Sn-Zn-O, have been studied as a most promising candidate for next-generation displays because of their high mobility, wide bandgap, and low process temperature [1, 2]. However, the long-term instability of the oxide semiconductor TFTs is always one of most critical issues, which results in the deterioration of device performance. Alternatively, in order to fabricated high stability TFTs with high mobility, several research groups have shown new possibilities with channel structure consisting of multilayers and superlattice structure. The formation of two-dimensional electron gas (2DEG) in the oxide superlattice structure with band discontinuities will dramatically enhance the mobility of the TFT devices [3, 4].

From the consideration mentioned above, we developed ZnO/Al_2O_3 superlattice structure by ALD as the active layer, which have obtained high-mobility high-stability TFT devices. The enhanced electrical properties were explained on the improved crystalline nature of the channel layer and passivation effect of Al_2O_3 layer by ALD [5]. In this study, the morphological and electrical properties of the TFTs with different ZnO/Al_2O_3 superlattice channel were investigated, and The TFTs with $ZnO/Al_2O_3/ZnO$ superlattice structure exhibited excellent performance.

2. Experiments

In this experiment, the conventional bottom-gate TFTs with ZnO/Al_2O_3 superlattice channel were fabricated on glass substrate by standard photolithography and lift-off technique. Figure 1(a) shows the schematic cross-sectional view of TFT devices with ZnO/Al_2O_3 superlattice structure. Figure 1(b) shows the micrograph of a fully processed bottom gate TFT. A 150nm In-Sn-O (ITO) gate electrode was firstly formatted on glass substrate using RF sputtering. Secondly, a 160nm SiO_2 layer was deposited as the insulator layer by PECVD at 100℃. Then a 15cycle Al_2O_3 film was deposited by ALD at 100℃ as the buffer layer. After that, a 100cycle ZnO/15cycle Al_2O_3/100cycle ZnO superlattice channel was formatted by ALD at 100℃. We also developed single ZnO channel and different superlattice channel for comparison, and also controlled the total thickness of ZnO is the same with 200 ALD cycle. Finally, the source and drain electrodes were deposited with a 150nm thickness ITO film. No intentional substrate heating was performed during each deposition step.

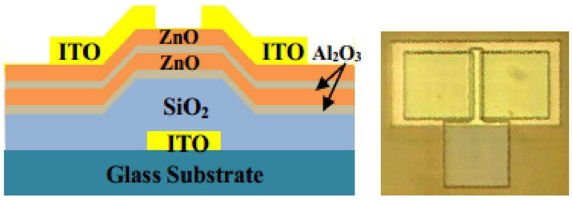

Fig.1 (a) Schematic Cross-sectional view and (b) Micrograph of the TFTs (W/L=100μm/10μm)

3. Results and discussions

The microstructural properties shown in Figure 2(a) and(b) were measured by high-resolution transmission electron microscopy (HRTEM), in order to characterize the crystalline of ZnO deposited by ALD and to investigate the effect of the Al_2O_3 buffer layer. In general, the ZnO layer will have island-like morphologies on the SiO_2 without buffer layer, due to the lack of chemical bonding sites such as O-H group. As the Al_2O_3 is hydrophilic, the Al_2O_3 buffer layer will induce layer-by-layer growth of ALD-grown ZnO layers, which will optimize the crystallinity of the ZnO layer and the interface state between channel/dielectric. Furthermore, as shown in figure 2 (a) and (b), the ZnO/Al_2O_3 superlattice structure shows

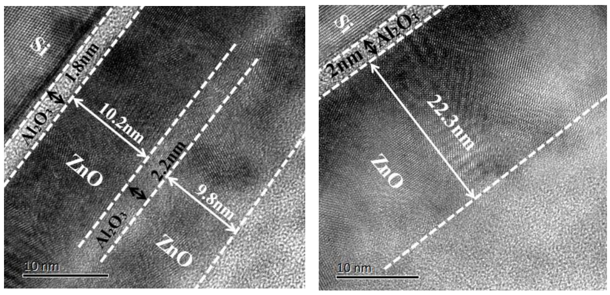

Fig.2 cross-sectional high-resolution TEM images of (a) ZnO/Al_2O_3 superlattice and (b) single ZnO sharper interface and better-arranged growth along the c-axis direction compared with single ZnO film. So as the insertion of the Al_2O_3 layer, the ZnO layer in the ZnO/Al_2O_3 superlattice structure shows significantly improved crystallinity, which will improve the performance of the devices. Figure 3 shows the transfer characteristics of TFTs fabricated with single ZnO and different ZnO/Al_2O_3 superlattice channel layers, which consist of ZnO/15cycle Al_2O_3/ZnO (named by ZAZ15), ZnO/30cycle Al_2O_3 /ZnO (named by ZAZ30), ZnO/15cycle Al_2O_3/ZnO/15cycle Al_2O_3/ ZnO (named by ZAZAZ). Table I shows the extracted electrical parameters of the TFTs. The TFTs with ZAZ15 structure exhibit optimum performance with low V_{TH} of 0.9V, high μ_{sat} of 109, steep SS of 162mV/decade and high I_{on}/I_{off} ratio of 3.15×10^8, which is superior to the TFTs' with single ZnO. It can be explained that high conduction band offset between the ZnO and Al_2O_3 can

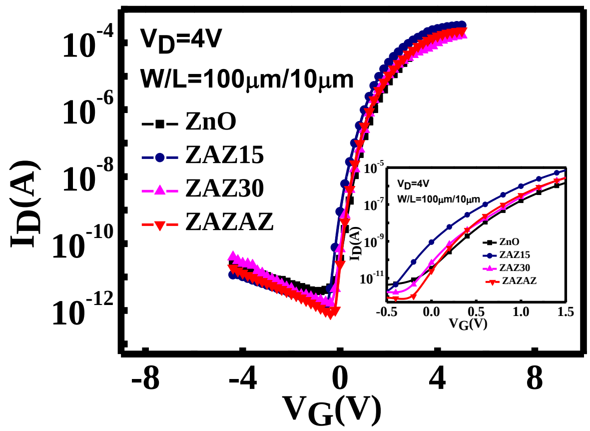

Fig.3 Transfer characteristics of the TFTs with single ZnO and ZnO/Al2O3 superlattice channel layers (W/L=100μm /10μm)

Table I The extracted electrical parameters of the TFTs

Channel	SS (mV/decade)	μ_{sat} (cm^2/V.s)	V_{TH} (V)	I_{on}/I_{off}
ZnO	254	49	1.77	3.76×10^7
ZAZ15	162	109	0.90	3.15×10^8
ZAZ30	173	51	1.10	4.97×10^7
ZAZAZ	164	62	1.22	1.2×10^8

confine the electrons in the potential well of ZnO, which induce high electron movement along the in-plane direction. Thus, in the superlattice channel, although the out-of-plane current decreased with the inserted Al_2O_3 layer, the mobility of charge carriers for the in-plane direction in the superlattice channel can be improved by achieving high crystallinity of the ZnO and confining the electron transport to the ZnO well layers [6]. Furthermore, the low operation voltage of the TFTs is surely realized thanks to the low threshold voltage and steep subthreshold feature resulting from the high performance of the thin Al_2O_3 dielectric. It also can be seen that the TFT with ZAZ30 and ZAZAZ have relatively worse performance than the TFTs' with ZAZ15, especially I_{on} and μ_{sat}. It is concerned with the thickness of the Al_2O_3 barrier layer. With the increasing thickness of well-insulated Al_2O_3 layer, the out-of-plane current generated by tunneling will significantly decrease, and the interface state between the ZnO/Al_2O_3 superlattice layers will relatively get worse, which have a significant effect on I_{on} and μ_{sat}. Consequently, the thickness of the Al_2O_3 layers should be ultra-thin for superlattice channel fabrication. However, the properties of ZAZAZ superlattice TFTs is relatively superior to the TFTs with ZAZ30, especially SS. It can be ascribed to the improved crystallinity of the ZnO induced by the insertion of double Al_2O_3 layers. Figure 4 shows the transfer characteristics of TFTs with ZnO/Al_2O_3 superlattice channel on different measurement points (W/L=100/10μm). Apparently, the curves almost coincide with each other, which suggests that TFTs with ZnO/Al_2O_3 superlattice channel have a good uniformity.

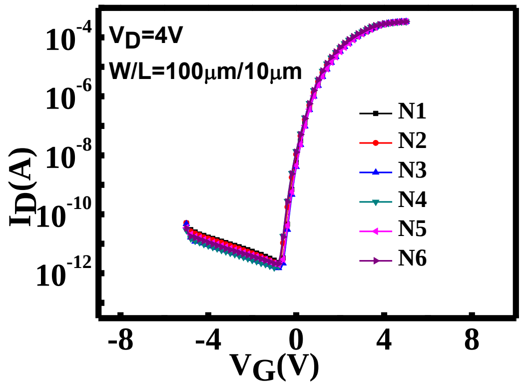

Fig.4 Transfer characteristics of the TFTs with ZnO/Al_2O_3 superlattice channel on different measurement points.

4. Conclusions

We have successfully fabricated high-performance TFTs with ZnO/Al_2O_3 superlattice channel by atomic layer deposition. The morphological and electrical properties of the TFTs with ZnO/Al_2O_3 superlattice channel were studied. The TFTs with ZnO/15cycle Al_2O_3/ZnO structure exhibited optimum performance with low V_{TH} of 0.9V, high μ_{sat} of 109$cm^2V^{-1}s^{-1}$, steep SS of 162 mV/decade and high I_{on}/I_{off} ratio of 3.15×10^8. The enhanced electrical properties were explained on the improved crystalline nature of the channel layer and passivation effect of Al_2O_3 layer.

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