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Fully Transparent Dual-active-layer ITO/TZO TFT Fabricated on Glass Substrate at low-temperature

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Abstract

Fully Transparent high-performance TFTs with dual-active-layer of ITO/TZO are successfully fabricated on glass substrate by sputter processing at low temperature (below 100℃). The dual-active-layer ITO/TZO TFTs perform better than single-active-layer TZO TFTs or ITO TFTs. We also find an optimized thickness (5nm) of the ITO layer for the dual-layer ITO/TZO TFT which exhibits excellent properties, with a high μ_s of 226 cm^2/Vs, a steep SS of 219 mV/dec, a low V_{th} of 0.8 V and high I_{on}/I_{off} ratio of 4.3×10^7. These competitive results make it a promising candidate for the transparent display applications.

1. Introduction

The metal-oxide thin film transistors have drawn considerable attention for their excellent electrical and optical properties in driving active matrix OLED and transparent displays applications. Metal-oxide-semiconductors, such as IZO, ZTO and IGZO, have been investigated frequently because of their superior electrical characteristics, direct printing, and low cost [1~3] etc. Researchers intended to optimize electric characteristics of metal-oxide TFTs in different ways such as using dual-gate structure and high-k dielectric and so on, but those will inevitably increase the cost of manufacturing or make it more complicated. What is more, traditional solution process requires high annealing temperature (above 450℃) to obtain high saturation mobility and good device performance. The high annealing temperature will largely increase the manufacturing cost [4].

To realize high-performance Sn-doped Zinc Oxide Thin-Film Transistors (TZO TFTs) and low manufacturing cost by conventional process, we studied a new active layer modulation: dual-active-layer (DAL) ITO/TZO TFTs. We investigated the properties of DAL ITO/TZO TFTs, compared to the properties of single-active-layer TZO or ITO TFTs, and find DAL ITO/TZO TFTs perform better than which of single-layer TZO TFTs or ITO TFTs. We also studied the effects of the thickness of ITO layer on the DAL ITO/TZO TFTs and find an optimized ITO thickness (5nm) for the dual-layer ITO/TZO TFT which exhibits excellent properties. All the process temperature was below 100℃. So it has low manufacturing cost. The competitive advantages of the ITO/TZO TFTs, such as the high performance and the low manufacturing cost, make sure that it can be a promising candidate for the display applications.

2. Device Fabrication

In our experiment, bottom-gate type dual-active-layer (DAL) ITO/TZO TFTs were fabricated on glass substrate by standard photolithography and lift-off technique, without any intentional substrate-heating. All the process temperature was below 100℃. Shown in Fig. 1(a) is the cross section of the devices. Firstly, a gate electrode was patterned and a 150-nm thickness ITO film was deposited by RF sputtering. Secondly, a SiO_2 film as gate insulator was fabricated by plasma-enhanced chemical vapor deposition (PECVD) at 80 ℃. Thirdly, an ITO film (5nm, 10nm, 15nm) and a TZO film (45 nm) are deposited in turn using RF sputtering as the double active layers. After patterning the source and drain electrode, a 150-nm thickness ITO film was deposited using RF sputtering and lifted off to form the source and drain electrodes. We studied the electrical characteristics of the single-layer channel TZO TFT, the single-layer channel ITO TFTs and the dual-layer (45-nm TZO and ITO with different thickness 5nm, 10nm, 15nm) channel ITO/TZO TFTs.

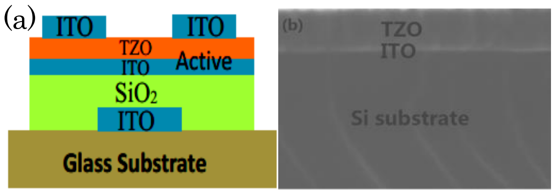

Fig.1 (a)Cross-section view of dual-layer channel channel ITO/TZO TFT. (b)Cross sectional SEM image of the dual-layer ITO/TZO film on silicon substrate.

3. Results and discussion

Figure 1(b) shows the cross-sectional SEM image of the DAL ITO/TZO film on silicon substrate. Figure 2 shows the transfer characteristics curves of single-layer channel TZO TFT, ITO TFT and the DAL ITO/TZO TFT. The curves were tested at V_{DS}=5V and the width-to-length ratio of channel is 100μm/10μm. The channel current of the ITO TFT stays almost constant as the gate voltage V_G changes. Compared to the single-layer channel TZO TFT and ITO TFT, the dual-layer channel ITO/TZO TFT exhibits better electrical properties: steeper subthreshold swing (SS) of 219 mV/dec, higher saturation mobility μ_s of 226 cm^2/Vs, lower V_{th} of 0.8V and higher on-off current ratio of 4.3×10^7. So we can come to a conclusion that dual-layer channel ITO/TZO TFTs perform better characteristics.

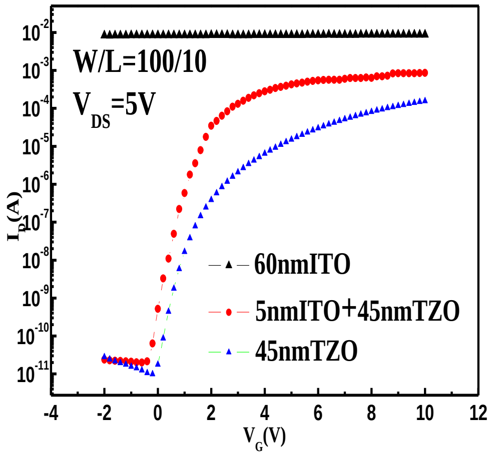

Fig. 2 Transfer characteristics curves of single-layer channel TZO TFT, ITO TFT and the dual-active-layer ITO/TZO TFT

The TFTs with single ITO active-layer is short between the source and drain when $V_{DS} \neq 0$. Thereby the channel shows properties as a resistance and the whole device acts as a capacitance. For single-layer channel TZO TFTs, the high-resistance TZO layer results in low off-state current. While V_G increases, the channel has good electrical conductivity because charges accumulate in the TZO layer, yielding a high on-state current. So the TZO channel controls the charge conductance to get a high on/off ratio and a suitable V_{th}. For DAL ITO/TZO TFTs, the ITO layer also plays an important role in current transmission for its high carrier concentration, which leads to larger I_{on}. The TZO layer provides a suitable I_{on}/I_{off} ratio and a low V_{th} for its low carrier concentration and its controlling ability in the charge conductance. Compared to TZO conducting layer, the thin ITO layer of the DAL ITO/TZO channel provides a higher carrier concentration, thereby maximizing the charge accumulation and yielding high saturation mobility μ_s. From the resistance point of view, the ITO layer reduces the channel resistance of ITO/TZO TFTs [4~6].

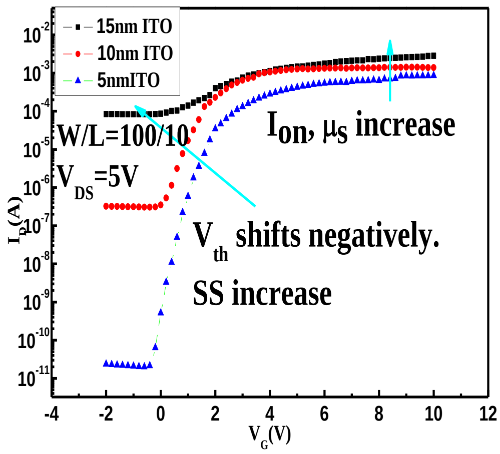

Fig. 3 Transfer characteristics curves of dual-layer ITO/TZO TFTs with various ITO-thickness

Fig. 3 illustrates the transfer characteristics of DAL ITO/TZO TFTs with various ITO-thicknesses. We can find that DAL ITO/TZO TFT with 5-nm ITO film exhibits the best performance of all. As the ITO film becomes thicker, the TFTs show poor device performance, such as higher SS and larger off-state current I_{off} and lower on-off ratio. We all know that the mobility and V_{th} of the TFTs are strongly related with the carrier concentration of the TFT active layer materials. Thicker ITO film can provide higher carrier concentration, the mobility of the TFT increase and the V_{th} is shifted more negatively. The high carrier concentration of the ITO film leads to high off-state current I_{off} [7]. The parameters of the TFTs were summarized in Table 1

Table I The extracted parameters of TFTs

Channel layer	Thick (nm)	μ(cm^2/V•s)	V_{th}(V)	SS (V/dec)	On/off ratio
TZO	45	26.3	2.79	0.274	1.5×10^7
ITO/TZO	5/45	226	0.803	0.219	4.3×10^7
ITO/TZO	10/45	450	0.527	0.458	3.1×10^3
ITO/TZO	15/45	542	0.401	1.08	34

4. Conclusions

In summary, high-performance full transparent bottom gate type dual-layer (ITO/TZO) channel thin film transistors (ITO/TZO TFTs) have been successfully fabricated on glass substrate at low-temperature. We studied effect of dual-layer channel ITO/TZO on the electrical properties of ITO/TZO TFTs. The results show that the dual-layer channel (ITO/TZO) TFTs, compared to the single channel TZO TFTs or ITO TFTs, exhibit better electrical properties, with a steep SS of 219 mV/dec, a high μ_s of 226 cm^2/V•s, a low V_{th} of 0.8 V and a high I_{on}/I_{off} ratio of 4.3×10^7. We also found the TFTs with 5-nm ITO active-layer film perform the best. The competitive advantages of the ITO/TZO TFTs, such as the high performance and the low manufacturing cost, make sure that it can be a promising candidate for the next generation transparent displays applications.

Acknowledgements

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