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Oxygen Partial Pressure Dependence of Ti-Zn-O Thin-Film Transistors Fabricated on Flexible Plastic Substrate at Low Temperature

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Abstract

Titanium-Zinc-Oxide (TiZO) thin-film transistors (TFTs) with bottom gate structure were successfully fabricated on flexible substrate at low temperature. Effects of oxygen partial pressure on performance of TiZO TFTs were studied. We found that the oxygen partial pressure has a significant impact on the performance of TiZO TFTs, and the TFT developed under 10% oxygen partial pressure exhibits optimum performance with low V_{TH} of 2.37V, high μ_{sat} of 125.4 $cm^2V^{-1}s^{-1}$, steep SS of 195mV/decade and high I_{on}/I_{off} ratio of 3.05×10^8. These results suggest that TiZO thin film is a promising candidate for high performance fully transparent flexible TFTs.

1. Introduction

In recent years, thin film transistors (TFTs) fabricated directly on flexible plastic substrates have been widely investigated for new large-area application such as rollable display, electronic skins or woven electronic for smart textiles due to the thin substrate and the simplified fabrication process [1, 2]. Furthermore, metal oxide semiconductors especially IGZO have become subject of intensive investigation, due to their transparency, low temperature and low cost process [3].However, the high driving voltage, large gate swing and low device mobility are still the critical issues when the IGZO TFTs are fabricated on flexible substrate. Besides, In is a rare and toxicant element on earth, which is detrimental to industrial production. Therefore, seeking alternative oxide semiconductors with good characteristics has become the key requirement.

From the consideration mentioned above, we developed Ti-doped Zinc Oxide(TiZO) as the active layer, because Ti dopants in Zinc-Oxide can suppress the free carrier generation and obtain an optimal carrier concentration, which optimizing the electrical performances of TFTs [4]. In this study, Effects of the oxygen partial pressure on electrical characteristics of TiZO TFTs have been studied. The TFT fabricated under the optimum condition exhibits excellent performance.

2. Experiments

In this experiment, the conventional bottom-gate TiZO TFTs were fabricated on PET plastic substrate by standard photolithography and lift-off technique. Figure 1(a) shows the schematic cross-sectional view of device. Figure 1(b) shows the micrograph of a fully processed flexible bottom gate TFT. A 150-nm In-Sn-O (ITO) gate electrode was firstly formatted on PET plastic substrate using RF sputtering at room temperature in pure Ar atmosphere. Secondly, a 200nm SiO_2 layer was deposited as the insulator layer by PECVD at 80℃. Then a 40nm TiZO layer was deposited by RF sputtering continuously at RT in various oxygen partial pressure using ZnO target doped with 3% TiO_2. The oxygen partial pressure (pO_2/pO_2+pAr) was 0%, 10%, 20% and 30%, respectively, under the working pressure (pO_2+pAr) of 1Pa. Finally, the source and drain electrodes were deposited with a 150-nm thickness ITO film. No intentional substrate heating was performed during each deposition step and the process temperature was below 100℃.

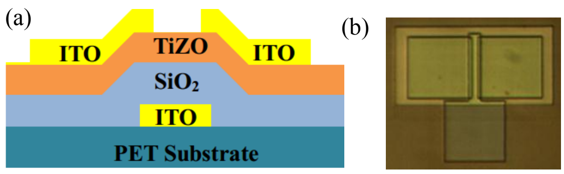

Fig. 1 (a) Schematic Cross-sectional view and (b) Micrograph of TiZO TFTs (W/L=100μm/10μm)

3. Results and discussions

The electrical properties of TiZO TFTs were measured using probe station and semiconductor parametric analyzer (Agilent 4156C). The channel length (L) and Width (W) of TiZO TFT were 10μm and 100μm, respectively. Figure 2 shows the transfer characteristics of TiZO TFTs fabricated at various oxygen partial pressure. It can be seen that the oxygen partial pressure has significant influence on the electrical performance of TiZO TFTs. The devices fabricated in pure Ar atmosphere, by contrast, have insufficient performance with a relatively high I_{off}, which is highly associated with the generation of abundant oxygen vacancy. Generally, a relatively large amount of oxygen vacancy induces the increase of carrier concentration, which will certainly result in high conductivity, namely, a high I_{off} [5]. However, with increasing oxygen partial pressure, I_{off} decreases dramatically, indicating that oxygen can certainly prevent the generation of oxygen vacancy. Table I shows the extracted electrical parameters of TiZO TFTs. As discussed before, the carrier concentration decreases with increasing oxygen partial pressure, leading to the decrease of

I_{on}. Whereas, the SS, μ_{sat} and V_{TH} show a non-monotonic change with increasing oxygen partial pressure. The device under 10% oxygen partial pressure exhibits optimum electrical characteristics with low V_{TH} of 2.37V, high μ_{sat} of 125.4cm^{2}V^{-1}s^{-1}, steep SS of 195 mV/decade and high I_{on}/I_{off} ratio of 3.05×10^8. As TiZO film with less free carrier exhibits better semiconductor characteristics and effectively enhance gate control, the performance of TiZO TFTs are significantly improved as oxygen partial pressure increases from 0% to 10%. However, when oxygen partial pressure increases from 10% to 30%, the device' performance degenerates. It can be explained that excess oxygen induces significant decrease of oxygen vacancy, leading to degeneration of V_{th} and μ_{sat}. Furthermore, excess oxygen can induce abundant interface defects between channel and dielectric, which lead to the degeneration of SS and μ_{sat}.

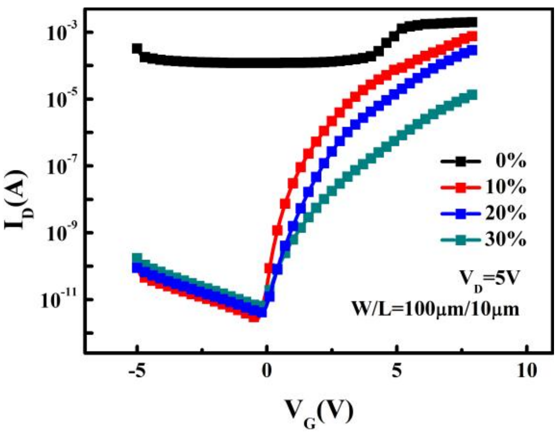

Fig.2 Transfer characteristics of TiZO TFTs fabricated at various oxygen partial pressure.

Table I The extracted electrical parameters of TiZO TFTs

pO_2/ pO_2+pAr	SS (mV/dec)	μ_{sat} (cm^2/V.s)	I_{on} (mA)	I_{on}/I_{off}	V_{TH} (V)
0%	658	41.8	1.98	1.64×10^1	3.20
10%	195	125.4	0.79	3.05×10^8	2.37
20%	356	64.0	0.31	7.51×10^7	2.86
30%	460	15.3	0.015	2.32×10^6	4.79

Figure 3 illustrates the XRD pattern of TiZO film with various oxygen partial pressure. A sharp peak was observed in the scan range which is almost match the diffraction peak position of ZnO, revealing that TiZO film was crystallized in hexagonal structure with a preferred c-axis orientation. It demonstrated that Ti atoms successfully replaced Zn sites in the lattice. Furthermore, the diffraction peak intensity decreases with the increasing oxygen partial pressure, indicating that the increasing oxygen partial pressure certainly suppresses crystallizing of TiZO film. Figure 4 illustrates the SEM images of TiZO TFTs with various oxygen partial pressure. The grain size deceases with increasing oxygen partial pressure. This is because excess oxygen accumulated at the grain boundaries and inhibited the growth of grain under high oxygen partial pressure [6], which also suppresses the crystallization of TiZO film.

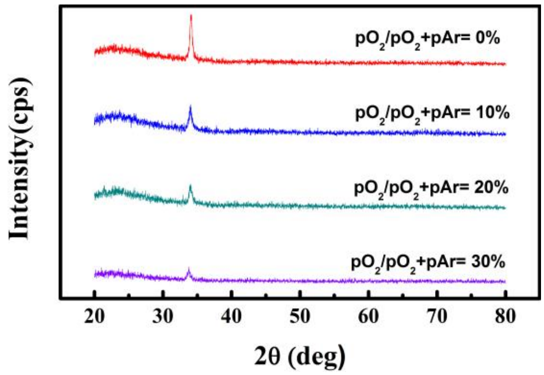

Fig.3 XRD pattern images of TiZO film deposited at various oxygen partial pressure.

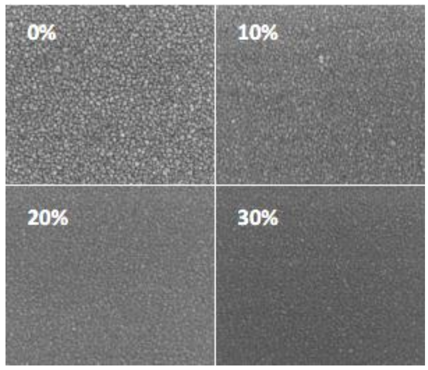

Fig.4 SEM images of TiZO TFTs deposited at various oxygen partial pressure.

4. Conclusions

The TiZO TFTs on flexible substrate at low temperature were successfully fabricated on flexible substrate. We varied the oxygen partial pressure and studied its impact on electrical characteristics of TiZO TFTs. The TFT fabricated under 10% oxygen partial pressure exhibits optimum performance with low V_{TH} of 2.37V, high μ_{sat} of 125.4 cm^{2}V^{-1}s^{-1}, steep SS of 195 mV/decade and high I_{on}/I_{off} ratio of 3.05×10^8. These results suggest that TiZO thin film is a promising candidate in transparent flexible electronics.

Acknowledgements

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