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High-performance Si-doped ZnO Thin-film Transistors Fabricated on Flexible Plastic Substrate at Low Temperature

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Abstract

Fully-transparent Silicon-Zinc-Oxide (SiZO) thin film transistors (TFTs) have been successfully fabricated on flexible plastic substrate at low temperature. We studied the influence of oxygen partial pressure during channel deposition on the performance of SiZO TFTs. It is demonstrated that the device prepared under 5% oxygen partial pressure exhibits optimum characteristics with low threshold voltage V_{th} of 2.1V, small subthreshold swing (SS) of 151mV/decade, high saturation mobility μ_{sat} of $102cm^2V^{-1}s^{-1}$ and high current ratio I_{on}/I_{off} of 4.9×10^8.

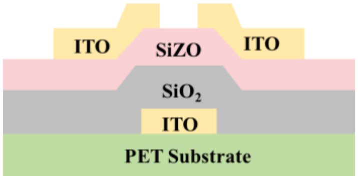
1. Introduction

Recently, flexible electronics have become a hot topic because they can be used to develop advanced optoelectronic applications, such as wearable computers, rollable displays and electronic skins[1-2]. The fabrication of thin-film transistors (TFTs) and other electronic device components on flexible substrate is a key technique to realize flexible electronics[2]. In order to fabricate TFTs with good performance, various novel oxide semiconductors for the active layer have been explored and In-Ga-Zn-O (IGZO) is one of the most popular materials[3]. However, Indium is rare and expensive, which is detrimental to quantity production. So it is necessary to find alternative oxide semiconductors with good characteristics.

In this paper, we developed Si-doped ZnO (SiZO) as the active layer. Here Silicon acts as a carrier suppressor due to higher bonding-strengths of silicon than that of zinc[4]. We investigated the effect of oxygen partial pressure on electrical properties of SiZO TFTs and achieved optimized characteristics.

2. Experiments

Staggered bottom-gate SiZO TFTs were fabricated by standard photolithography and lift-off technique, and are illustrated in Figure 1 (a). Samples on PET plastic substrate had a 150nm In-Sn-O (ITO) bottom gate by RF magnetron sputtering at room temperature in pure Ar atmosphere. In order to form the insulator layer, a 150nm SiO_2 layer was deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD) at 80°C. Subsequently, we deposited the SiZO film as active layer by RF magnetron sputtering in different oxygen partial pressure. The oxygen partial pressure (pO_2/pO_2+pAr) was 0%, 5%, 15% and 25% respectively, under a total working pressure (pO_2＋pAr) of 1.0 Pa at room temperature. After that, for the sake of forming the gate insulator and the active channel, two layers were lifted off together. Finally, source and drain electrodes were patterned and a 150nm ITO film was deposited as source and drain electrodes by RF magnetron sputtering in pure Ar atmosphere. The devices exhibit perfect flexible as shown in Figure 1 (b).



(a)

(b)

Fig. 1 (a) Cross-sectional schematic of the SiZO TFT device. (b) Picture of SiZO TFTs on a bent flexible PET substrate.

3. Results and Discussion

Figure 2 shows the transfer characteristics of SiZO TFTs at different oxygen partial pressure measured by a semiconductor parameter analyzer (Agilent 4156C). The extracted electrical parameters of SiZO TFTs with different oxygen partial pressure from transfer characteristics of SiZO TFTs are demonstrated in Table I. It can be found that oxygen partial pressure of active layer plays an important role in the electrical performances of SiZO TFTs. As for the device fabricated under 0% oxygen partial pressure, it can not be switched off due to high carrier concentration. Because the device is unable to deplete the semiconductor with reasonable V_G, it is not usable as transistors[5]. So we do not calculate the electrical parameters of the device fabricated under 0% oxygen partial pressure. With the increase of oxygen partial pressure, V_{th} and subthreshold swing SS increase while I_{on} decreases. This phenomenon can be explained by the mechanism of oxygen vacancy. For n-type oxide semiconductor, oxygen vacancy is important in conductivity mechanism because oxygen vacancy generates two free electrons in the conductor band and serves as a shallow donor. When the oxygen partial pressure increases, oxygen can restrain the generation of oxygen vacancy and decrease carrier concentration, resulting in the decrease of I_{on} and the increase of V_{th}. In addition, extra oxygen can lead to interface defects between the active layer and dielectric. Thus, with the increase of oxygen partial pressure, the value of SS becomes larger.

It can be seen that the device with 5% oxygen partial pressure reveals the optimum electrical characteristics with low V_{th} of 2.1V, small SS of 151mV/decade, high μ_{sat} of $102cm^2V^{-1}s^{-1}$ and high I_{on}/I_{off} of 4.9×10^8. When the oxygen partial pressure increases from 0% to 5%, SiZO TFTs' transfer characteristics are dramatically improved due to the decrease of overmuch free carriers. Nevertheless, with the oxygen partial pressure rising from 5% to 25%, interface defects increase leading to the degeneration of device.

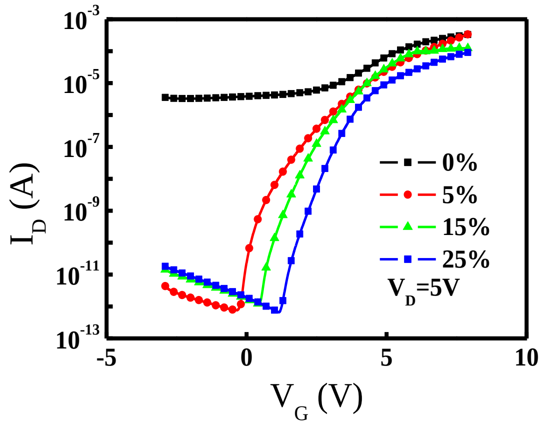


Fig. 2 Transfer characteristics of SiZO TFTs with different oxygen partial pressure.

Table I The extracted electrical parameters of SiZO TFTs with different oxygen partial pressure.

$O_2/Ar+O_2$ (%)	SS (mV/dec)	I_{on}/I_{off}	V_{th} (V)	μ_{sat} (cm^2/V.s)	I_{on} (mA)
5	151	4.9×10^8	2.1	102	0.36
15	175	1.1×10^8	2.4	114	0.13
25	219	1.5×10^8	2.6	45	0.09

Figure 3 exhibits the X-ray diffraction pattern (XRD) of SiZO thin film deposited on silicon substrate at room temperature. Two sharp peaks are observed. The peak near 33° is caused by silicon substrate(Si 200). The peak of SiZO is nearly at 2θ≈34.2°, which is in accordance with the diffraction peak position of ZnO, indicating that the SiZO film was crystallized with a preferred c-axis orientation.

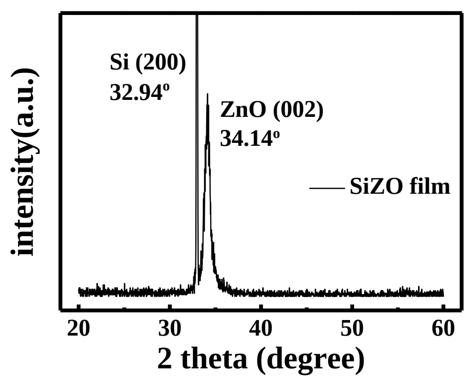


Fig. 3 The XRD pattern of SiZO thin film deposited on silicon substrate.

The AFM morphology images of SiZO films with different oxygen partial pressure are shown in Figure 4. The root mean square roughness of SiZO film with 0%, 5%, 15% and 25% O_2 partial pressure are 0.61nm, 0.41nm, 0.32 nm and 0.30 nm, respectively. It can be explained that under high O_2 partial pressure, excess oxygen accumulates at grain boundaries and suppresses the grain growth resulting in smaller grain size and smaller roughness[6].

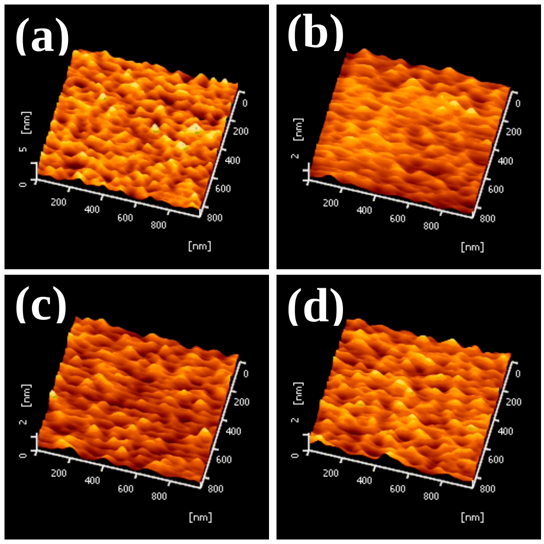


Fig. 4 The AFM morphology of SiZO film with different oxygen partial pressure (a)0%; (b)5%; (c)15%; (d)25%..

4. Conclusions

In summary, we have fabricated good performance SiZO TFTs on flexible substrate. We have also changed oxygen partial pressure during the sputtering of SiZO thin film and studied its influence on the electrical characteristics of SiZO TFTs. The device prepared under 5% oxygen partial pressure exhibits optimum characteristics with low V_{th} of 2.1V, small SS of 151mV/decade, high μ_{sat} of $102cm^2V^{-1}s^{-1}$ and high I_{on}/I_{off} of 4.9×10^8, which proves that SiZO TFT is a promising candidate for flexible displays.

Acknowledgements

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