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

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Abstract

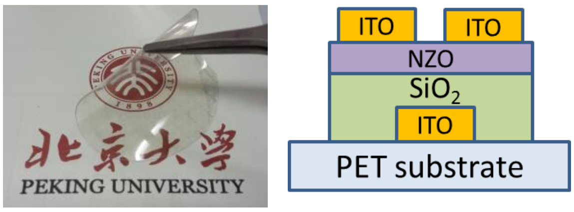
We have fabricated Ni-doped ZnO thin-film transistors (NZO TFTs) on flexible plastic substrate at low temperature. To optimize the performance of NZO TFTs, the effect of different oxygen partial pressure during channel deposition on electrical properties of NZO TFTs was studied. We found that oxygen partial pressure has a significant influence on the performance of NZO TFTs. Finally, it is demonstrated that the NZO film with 100% Ar sputtering ambience during channel deposition exhibited the best electrical properties, with a drain current on/off current ratio of 10^8, a threshold voltage of about 2.59V, a subthreshold swing of about 233mV/dec, and a field effect mobility of 118.9cm^2/V•s in saturation region. The results showed that Ni-doped ZnO is a promising candidate for the channel material of high performance flexible fully-transparent TFTs.

1. Introduction

Recently, flat panel display has developed rapidly being used in televisions, computer monitors, cellular phones, mp3 players etc. Because of its light weight and flexibility, flexible electronics has become a hot topic [1]. Thin-film transistors (TFTs) play an important role in realizing its functions. ZnO TFTs have attracted increasing attention because of their higher mobility than a-Si:H TFTs. And indium gallium zinc oxide (IGZO) is considered as the promising material for next generation display technique, because of its high field effect mobility and I_{on}/I_{off} ratio [2-4]. However, In and Ga both are rare elements on the earth and expensive. Therefore, we should find a cheaper semiconductor material for the display technique. In this article, we investigated Ni-doped ZnO (NZO) as the channel material. United now there have been seldom reports about Ni-doped ZnO as the channel material of TFTs. We studied the effect of oxygen partial pressure on electrical properties of NZO TFTs and achieved good performance.

2. Experiments

In this fabrication, we use a kind of flexible PET plastic material as the substrate. First, the substrate was patterned. Then it was deposited with a 150 nm ITO layer by RF magnetron sputtering and lifted off to form the bottom gate contact. Second, we deposited a 150 nm SiO_2 layer by PECVD. Subsequently a 60nm NZO layer was deposited by RF magnetron sputtering. After that, the two layers were lifted off together to form the gate insulator and the active channel. Afterwards the source and drain electrodes were patterned and deposited with a 150 nm ITO layer by RF magnetron sputtering and lifted off to form source and drain contacts. The sputtering chamber was pre-pumped to 5×10^{-4} Pa as the base vacuum pressure. The oxygen partial pressure (pO_2/pO_2+pAr) was 0%, 10%, 20% and 30% respectively, under a total working pressure (pO_2＋pAr) of 1.2 Pa. The RF power was maintained at 70 W. The whole fabrication was completed at low temperature. Figure 1(a) shows picture of the NZO TFT on a bent flexible PET substrate; figure 1(b) shows the schematic structure of bottom-gate NZO TFTs.



(a) (b)

Fig. 1. (a) Picture of NZO TFTs on a bent flexible PET substrate. (b) The schematic structure of flexible bottom-gate NZO TFTs.

3. Results and Discussion

Fig. 2 shows the representative transfer characteristics of NZO TFTs measured by a semiconductor parameter analyzer (Agilent 4156C). Table I shows the extracted electrical parameters of NZO TFTs with various oxygen partial pressure from transfer characteristics of NZO TFTs. It can be seen that the oxygen partial pressure during the growth of the NZO thin film has significant effects on the electrical performances of the NZO TFTs. With the increase of oxygen partial pressure, the I_{on} and the saturation mobility μ_s decrease, while the threshold voltage V_{th} and the subthreshold swing SS increase. As the n-type oxide semiconductor, a well-known mechanism is that the oxygen vacancy generates two free electrons in the conductor band and works as a shallow donor. The electron concentration decreases with the increasing oxygen partial pressure during the growth of the NZO film, leading to the increase of V_{th} and the decrease of μ_s. As a result, the I_{on} decreases. Generally, the TFT with higher V_{th} has more defects at the interface between the channel and the dielectric, leading to higher subthreshold swing SS. The TFT with NZO film growing under 0% oxygen partial pressure exhibited the best electrical properties, with an on/off current ratio of 10^8, an off current in the order of 10^{-13} A, a threshold voltage about 2.59 V, a saturation mobility of about 118.9 $cm^2V^{-1}s^{-1}$, and a subthreshold swing of about 0.233 V/dec. These electrical properties suggest quite good switching property.

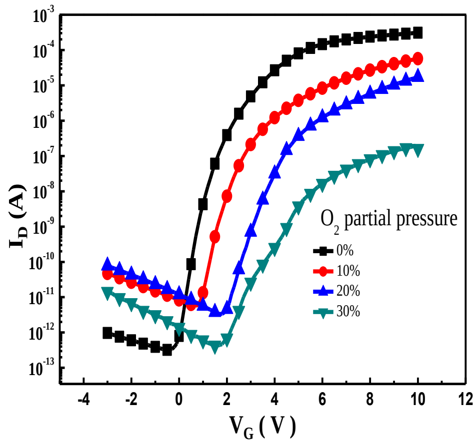


Fig. 2. Representative transfer characteristics of NZO TFTs with various oxygen partial pressure.

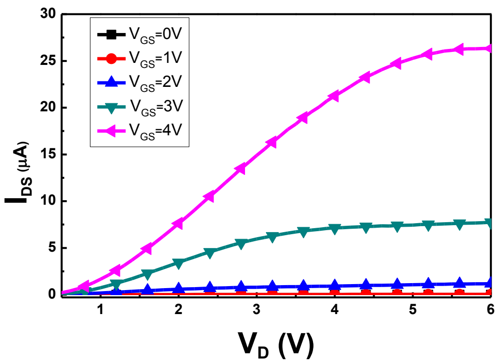


Fig. 3. Output characteristics of NZO TFT with drain voltage ranging from 0 to 6V, when oxygen partial pressure is 0%.

The output characteristics of NZO TFT with the optimized oxygen partial pressure are shown in Fig.3. V_{DS} scan from 0 to 6 V under different gate voltage of 0, 1, 2, 3 and 4 V. The device presents good linear characteristics and a clear saturation at high drain biases.

The SEM images of NZO TFTs with various oxygen partial pressure are shown in Figure 4. Obviously, as the O_2 partial pressure increased from 0% to 30%, the grain size of NZO films was becoming smaller and smaller. It can be explained that the grain growth is inhibited by excess oxygen segregation at grain boundaries when O_2 partial pressure is high, referring to the previous study about ZnO films.[5] And the carrier mobility depends exponentially on the grain size.[6] As O_2 partial pressure increased, the grain size decreased, resulting in the increase of the grain boundary, i.e. the scattering centers for the carriers, and finally reduced the carrier mobility, which corresponded to the extracted mobility of NZO TFTs in Table I.

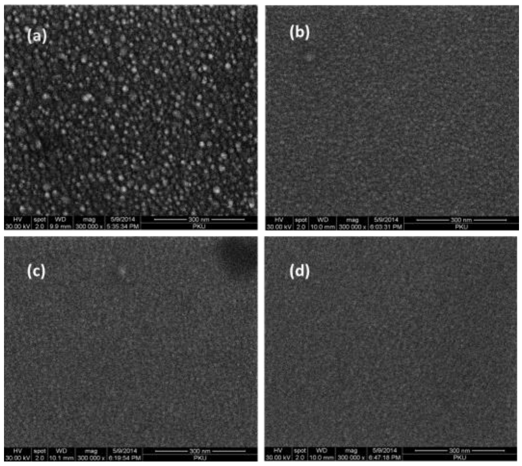


Fig. 4. SEM images of NZO TFTs with various oxygen partial pressure (a) 0%;(b) 10%;(c) 20%;(d) 30%.

Table I The extracted electrical parameters of NZO TFTs with various oxygen partial pressure.

oxygen partial pressure	μ ($cm^2V^{-1}s^{-1}$)	V_T (V)	SS (V/dec)	I_{on}/I_{off}
0%	118.9	2.59	0.233	9.62×10^8
10%	7.68	2.86	0.303	9.86×10^6
20%	2.8	3.98	0.403	5.09×10^6
30%	0.053	4.34	0.525	3.72×10^5

4. Conclusions

In conclusion, we have fabricated NZO TFTs with nice characteristics. We have also studied the effect of oxygen partial pressure during the growth of NZO thin film on the electrical properties of the NZO TFTs on flexible plastic substrates at low temperature, and achieved an optimized growing condition for NZO films as the channel material. The NZO TFTs as-fabricated exhibit excellent electrical properties, with an on/off drain current ratio of 10^8 , an off current in the order of 10^{-13} A, a threshold voltage about 2.59 V, a saturation mobility of about 118.9 $cm^2V^{-1}s^{-1}$,and a subthreshold swing of about 0.233 V/dec. It can demonstrate that Ni-doped ZnO TFTs on flexible plastic substrates are promising for flexible displays.

Acknowledgements

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