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The Effect of Rapid Thermal Annealing on the Electrical Characteristics of ZnO TFTs

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1. Introduction

Zinc oxide (ZnO) is a semiconductor material well suited for fabricating electronic devices such as transparent thin film transistors (TTFTs)[1-4]. The characteristics of ZnO TFTs reported in the literature outperform Si-based TFTs in terms of drift mobilities as high as 27 $cm^2/V\cdot s$ and ON/OFF current ratio up to 10^7. ZnO based TFTs exhibiting transparent characteristics as well as excellent electrical characteristics are promising technologies to realize transparent electronic display devices. However, there are couple of technical challenges to be overcome to achieve manufacturability of ZnO based TTFTs. They include electrical and thermal stabilities, and low leakage characteristics of the devices. The leakage current, which can be significant for large drain to source bias limits the time for which the video information can remain in a pixel before being refreshed in AMLCDs. In this work, we report the effect of Rapid Thermal Annealing (RTA) and the subsequent N_2O plasma treatment on the electrical performance of ZnO TFTs. The post-processing in N_2O plasma remarkably improved the performance of TFTs in terms of OFF current and the ON/OFF current ratio.

2. Device Fabrication

ZnO-based bottom gate TFTs were fabricated using a RF magnetron sputtered ZnO of 250 nm thick and 200 nm of PECVD silicon nitride gate dielectric on a corning 1737 glass susbstrates coated with 200 nm indium tin oxide. The schematic cross-sectional view and the SEM top view of the fabricated TFTs are shown in Fig. 1(a) and Fig. 1(b) respectively.

3. Results and Discussions

I_d-V_{ds} and I_d-V_{gs} characteristics, after an RTA at 270°C for 5 minutes in N_2 ambient, of the TFTs with W/L=200/20 μm are shown in Fig. 2(a) and Fig. 2(b) respectively. This annealing step is necessary since the as-fabricated devices show very low drain currents. The off-current is about 10^{-8} A and the ON/OFF current ratio is only about 3×10^3. Considering that the gate current is only about 10^{-10} A, it is clear that the OFF current is not limited by the gate leakage current but by the current flow in the undepleted region of the ZnO channel near the top surface. In order to see the influence of the N_2O plasma treatment on the off-current, we have subjected the annealed samples to N_2O plasma at 200°C for 5 minutes in a PECVD chamber. The output and the transfer characteristics obtained after the N_2O plasma treatment are shown in Fig. 3(a) and Fig. 3(b) respectively. After the N_2O treatment, the ON/OFF current ratio has improved to higher than 10^5 from 3×10^3. Also, it may be noted that there is a slight decrease in the ON current value. The improvement of OFF current from 2×10^{-8} A to 10^{-10} A may be due to the incorporation of oxygen into ZnO from the N_2O plasma. Since oxygen vacancies act as n-type dopants [5], the reduction of oxygen vacancies can decrease the carrier concentration at the top region of the channel and resulting in the low OFF current. Also, p-type semiconductor properties have been reported in nitrogen doped zinc oxide [6]. In the present case, to see if nitrogen from N_2O plasma is playing any role in the improvement of on/off current ratio, we have subjected one set of samples to N_2 plasma under the same plasma conditions. The transfer characteristics obtained from the TFTs before and after the N_2 plasma treatment are shown in Fig. 4. It can be seen that the devices show almost the same characteristics, which suggests that the better on/off ratio obtained after the N_2O plasma treatment is due to the presence of oxygen

4. Conclusions

The post-processing on the ZnO TFTs by utilizing N_2O plasma improved OFF current ON/OFF current ratio of the devices more than an order of magnitude. The off-current of the devices decreased from 2×10^{-8} to 10^{-10} A and the ON/OFF current ratio increased from 3×10^3 10^5. It can be concluded that oxygen present in the N_2O modifies the top region of the ZnO channel layer during the N_2O plasma treatment. Oxygen vacancies, acting as n-type dopants, near the top region of the ZnO were reduced by the N_2O plasma treatment, resulting in low OFF current and high ON/OFF current ratio.

References

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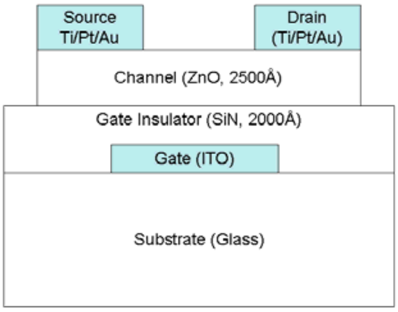


Fig. 1 (a) Schematic cross-sectional view of bottom gate TFT structure

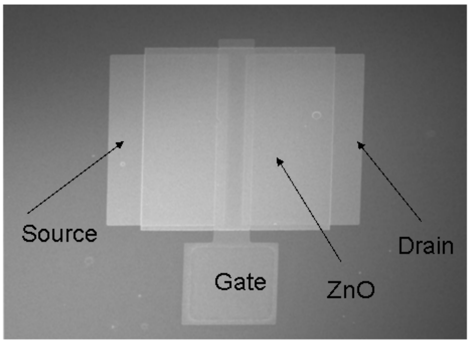
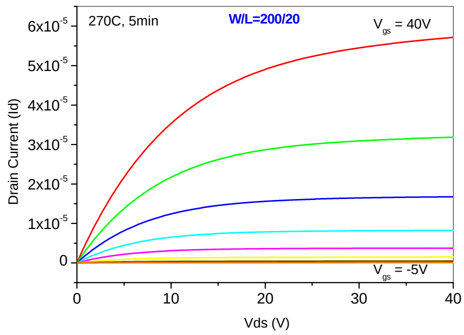
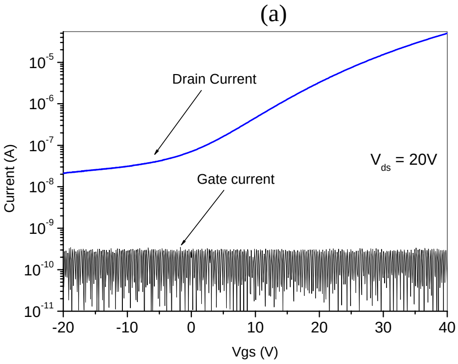


Fig. 1(b) SEM top view of the fabricated TFT

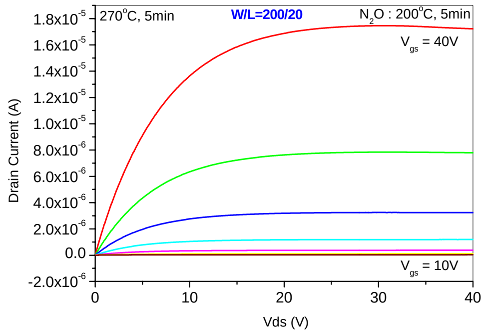


(a)

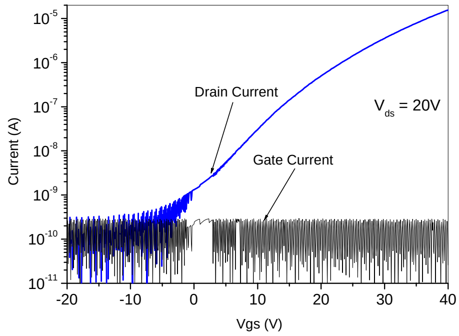


(b)

Fig. 2 Characteristics of ZnO TFTs with W=200 μm and L=20 μm, after RTA at 270°C for 5 min in N_2 ambient. (a) Output characteristics with V_{gs} from 40 V to -5 V in steps of -5 V, (b) transfer characteristics and gate leakage current at V_{ds} of 20V



(a)



(b)

Fig. 3 Characteristics of ZnO TFTs with W=200 μm and L=20 μm, after the combined treatment of RTA at 270°C for 5 min in N_2 ambient and N_2O plasma treatment at 200°C for 5 min. (a) Output characteristics with V_{gs} from 40 V to -5 V in steps of -5V, (b) transfer characteristics and gate leakage current at V_{ds} of 20V

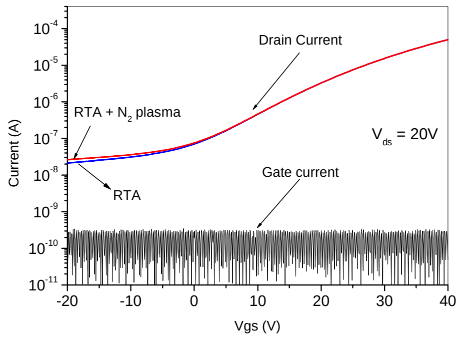


Fig. 4 Transfer characteristics and gate leakage current at V_{ds} of 20 V. The ZnO TFTs with W=200 μm and L=20 μm, were treated by RTA at 270°C for 5 min in N_2 ambient and by N_2 plasma at 200°C for 5 min.