Thin-film transistors based on zinc oxide films by ultrasonic spray pyrolysis

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The application of Zinc Oxide (ZnO) films by ultrasonic spray pyrolysis at 250, 300 and 450°C as active layer in thin-film Transistors (TFTs) is presented. The performance of the devices shows an unexpected behavior in function of the deposition temperature. The ZnO films were deposited from 0.2 M precursor solution of Zinc acetate in methanol, using air as carrier gas. 70nm-thick ZnO was deposited over 100 nm-thick aluminum electrodes patterned on 50 nm-thick thermally grown SiO_2 on highly doped Si wafers. The highly doped Si wafer was used as the gate electrode. The ZnO TFTs at 250°C showed field-effect mobilities around of 0.05 cm^2/Vs and threshold voltages of 8 V.

Keywords: ZnO; electrical properties; thin film transistors.

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1. Introduction

In the last years, Zinc Oxide (ZnO) is attractive due to its application in thin-film transistors (TFTs) and other devices. ZnO films can be obtained by several techniques such as pulsed laser deposition, sputtering, chemical vapor deposition, spray pyrolysis, etc. [1-6]. Where spray pyrolysis offers low-cost, simplicity, compatibility with large-area substrates and no need of high vacuum [6,7]. Although, oxide TFTs fabricated by spray pyrolysis have already been demonstrated [7-10], the results reported show that the main limitation is the need to use high temperatures to achieve good electrical performance. Then, it is necessary reduce the temperature of deposition to values close to the temperature of fabrication of a-Si TFTs. In order to reach this goal, the application of ZnO films obtained by ultrasonic spray pyrolysis at 250°C as active layer in TFTs is presented. Whereas ZnO films obtained at 300 and 450°C were used for comparison. There are different ways to spray the solution onto the substrates, Ortel *et al*. [9] sprayed the solution with a perfume atomizer. While in this work, we used an ultrasonic humidifier and air as carrier gas to spray the solution onto the samples.

2. Experiment

The ZnO films were deposited using a typical home-made ultrasonic spray pyrolysis deposition system adapted from an ultrasonic humidifier (Heaven Fresh), from 0.2 M precursor solution of Zinc acetate in methanol, using air as carrier gas at flow rate of 467 sccm at 250, 300 and 450°C. For the fabrication of the ZnO TFTs, 70 nm-thick ZnO was deposited over 100 nm-thick aluminum electrodes patterned on 50 nm-thick thermally grown SiO_2 on highly doped Si wafers. The highly doped Si wafer was used as the gate electrode. Figure 1 shows the cross section of the devices fabricated. The electrical characteristics were measured using the Keithley-4200 Semiconductor Characterization System, under dark conditions and room temperature.

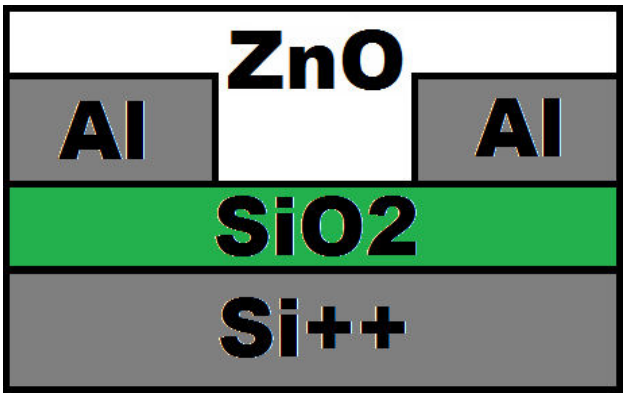

FIGURE 1. Cross section of the fabricated bottom-gate ZnO TFT (not to scale).

3. Results and discussion

Figure 2 shows the transfer characteristics, in saturation regime (Vds = 20 V), of the ZnO TFTs at 250, 300 and 450°C. The observed on/off-current ratio was almost 10^3 for TFTs with ZnO films at 250°C, while for ZnO films at 300 and 450°C were 10^2 and 10^1. On the other hand, the electron mobility and threshold voltage VT were extracted from the square root of Ids versus Vgs in the saturation regime (inset on figures) [11], where the ZnO TFTs at 250°C showed field-effect mobilities around of 0.05 cm^2/Vs and threshold voltages of 8 V, while ZnO TFTs at 300°C showed field-effect mobilities around of 1.3 cm^2/Vs and threshold voltages of

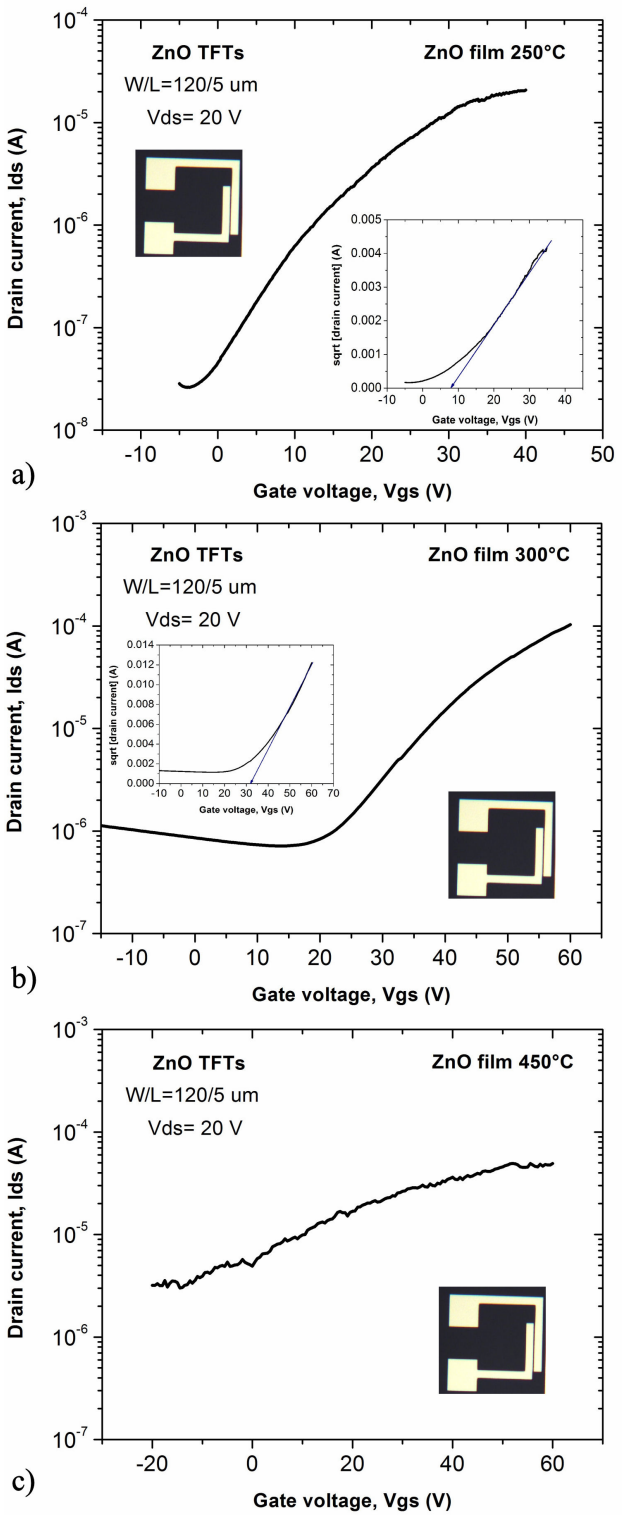

FIGURE 2. Transfer characteristics of the low-temperature ZnO thin-film transistors. a) ZnO film at 250°C, b) at 300°C and c) at 450°C. Inset: top-view and square root of Ids versus Vgs of the fabricated ZnO TFTs.

32 V. For ZnO TFTs at 450°C were no possible to extract parameters since they did not show a clear transfer characteristic. It is important to note, that as the deposition temperature

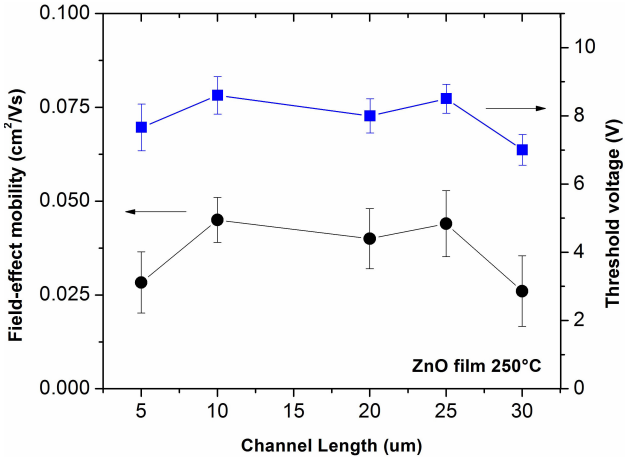

FIGURE 3. Field-effect mobility and threshold voltage V_T as function of the channel length for ZnO TFTs at 250°C.

increases the off-state is larger, or in other words, is more difficult to modulate the electron-channel in the ZnO film. Contrary to the results obtained by [7] at higher temperatures of deposition, the performance of the ZnO TFTs impoverishes. It is complex to understand the reason why we found an opposite tendency as the deposition temperature increases. From the X-ray diffraction measurements (not shown here) the ZnO films pass from amorphous to polycrystalline structure with a preferential orientation in (002) plane as the deposition temperature increases, as previously reported by other authors. This agrees with the field-effect mobilities extracted, however, from the transfer characteristics, it can be seen an increase in the threshold voltage and a larger off-state as the deposition temperature increases, also the on/off-current ratio is reduced. All of these can be possible if the ZnO behaves as a semi-metal as the structure acquires a polycrystalline structure, which can explain why is more difficult to modulate the electron-channel. It is well-known, that ZnO films are highly dependent on the deposition conditions and post-treatments conditions, since they result in different surface conditions and defects density distribution. For this reason, further material research is necessary to address the above assumption.

The results obtained from the ZnO TFTs at 250°C are comparable with the reported in Ref. 7. They reported carrier mobilities from 20 to 0.001 cm^2/Vs and on/off current ratios from 10^6 to 10^1 at deposition temperatures from 500°C to 200°C. Although in Ref. 7 reported a dependence of mobility on channel length, it can be observed in Fig. 3 that apparently there is no dependence of mobility and V_T on channel length in our devices. Figure 4 shows the output characteristics of the ZnO TFTs. It can be seen effects of current crowding at low values of Vds, due to a high contact resistance resulted by an Al_2O_3 layer formed in the metal-semiconductor interface during the fabrication of the devices. This high contact resistance reduces the on/off-current ratio and masks the real value of the electron mobility. Moreover, it can be appreciated a similar tendency as in the transfer characteristics, where the performance of the ZnO TFTs impoverishes as the

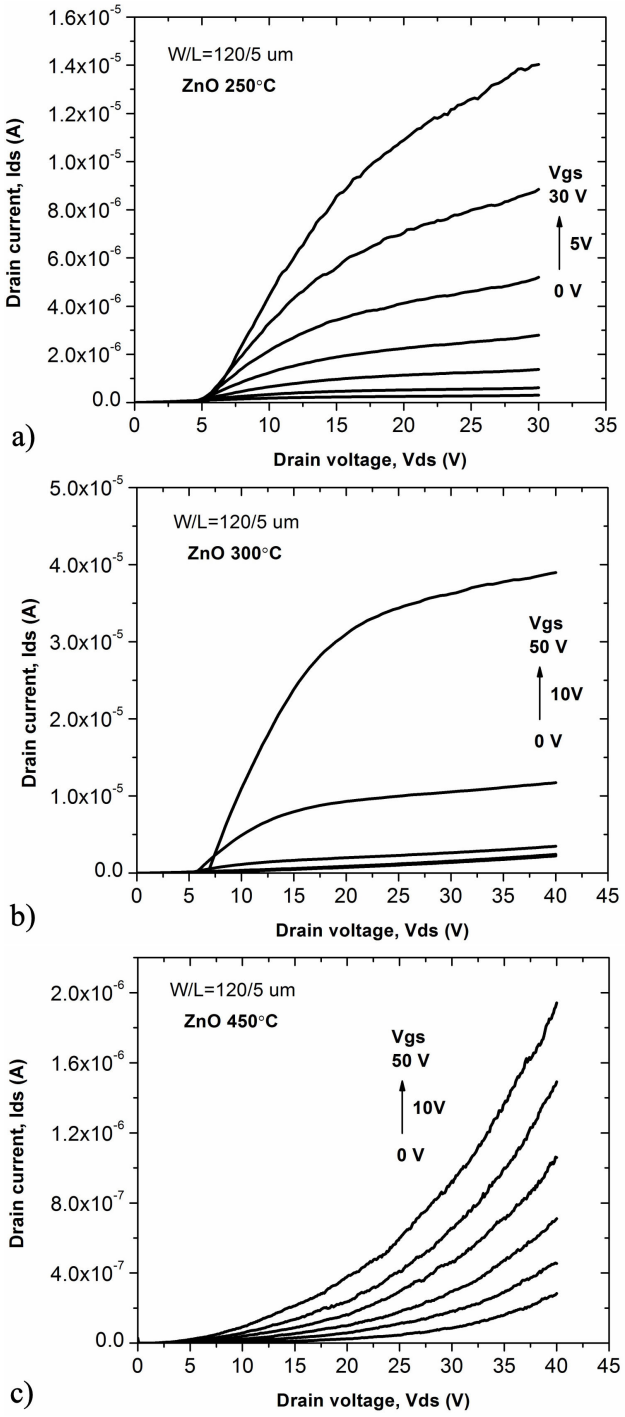

FIGURE 4. Output characteristics of the low-temperature ZnO thin-film transistors. a) ZnO film at 250°C, b) at 300°C and c) at 450°C.

deposition temperature is increased. However, output characteristics of ZnO TFTs fabricated at low-temperature by spray pyrolysis have not been reported. From the transfer characteristics, there is no appreciation of effects of high leakage current.

4. Conclusions

The application of ZnO films by ultrasonic spray pyrolysis at 250°C in thin-film transistors are demonstrated. At higher temperatures of deposition the performance of the ZnO TFTs impoverishes. Apparently, the ZnO film may behaves as a semi-metal as the structure acquires a polycrystalline structure. The ZnO TFTs shown effects of high contact resistance resulted by a low-quality metal-semiconductor interface. There is no appreciation of effects of high leakage current due to the thinner gate dielectric in the transfer characteristics.

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