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ZnO Thin Film Transistor with U-shape Active Layer for High Performance Application

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Abstract

In this paper, we proposed ZnO TFT with U-shape active layer for the device performance enhancement including threshold voltage (V_{th}) modulation without any additional masks. The U-shape ZnO TFT can control Vth by thinning the active layer thickness without contact resistance degradation. The fabricated device shows better electrical properties than standard bottom gate ZnO TFT. And a tunable V_{th} range is from -8.2 to -2.4 V. Moreover, this structure is more stable in thermal stress than previous metal back gate structure.

1. Introduction

Zinc oxide (ZnO) based thin film transistors (TFTs) have attracted much attention as a display drive device due to their high field-effect mobility, low-temperature processing at < 200 ˚C, and high uniformity over large areas compared with a-Si TFTs [1]. Sharp is the first company to mass produce ZnO-based (IGZO) TFT since 2012. LG started mass produce IGZO TFT for their 55” AMOLED TV since early 2013. For this application, a bottom gate structure has been widely used due to lower fabrication cost. But this structure has unintended back channel problem. The problem causes the change of threshold voltage (V_{th}) and degrades the device performance [2]. Ref. [3] of Park et al., has showed that V_{th} of bottom gated IGZO TFTs can be varied by controlling the IGZO thickness. In case of crystalline zinc oxide, however, the thickness changes of ZnO will affect the overall device performance. Ref. [4] of Lim et al., fabricated double gate IGZO TFTs. The Pt back gate helps the suppression of an unintentional accumulation channel at the IGZO channel surface. Similarly, our group has also proposed the body metal contact structure (Schottky-contact-merged, SCM) ZnO TFTs for V_{th} modulation [5]. In SCM TFTs, a floated body metal contact is formed whose work function is higher than the active material. Then, the channel surface is depleted and the back channel can be suppressed due to the work function difference. But we found that this structure is weak in the high temperature because the promoted free carrier activity reduces the depletion effect. Considering the display device produces heat while operating, it is needed to improve the body metal structure for V_{th} modulation. In this study, we propose a ZnO TFT with U-shape active layer for the device performance enhancement including V_{th} modulation.

2. Experiment

Thermal SiO_2 of 120 nm was grown on pre-cleaned heavily doped n-type silicon wafer. A 40 nm active layer (ZnO target; the Ar/O_2 mixed gas flow ratio was 1:20 sccm) was deposited by RF magnetron sputtering with shadow mask. And, 60 nm more ZnO was deposited using source/drain (S/D) shadow mask to form a U-shape active layer. And then, the Ti S/D electrodes and Au body metal were formed with RF magnetron sputtering. Finally, the samples were thermal annealed under air ambient conditions of 300 °C for 1h. Fig. 1 shows cross section of the suggested bottom gated U-shape ZnO TFT.

3. Result and Discussion

Fig. 2 shows I_{DS}-V_{GS} characteristics of the fabricated U-shape with the conventional devices. In the conventional ones, the ZnO active layer thickness is 40nm or 100nm while 40nm in U-shape. V_{th} is shifted to the positive direction as the active thickness decreases from 100 to 40 nm. This is because thining the thickness of ZnO cuases less free carrier concentraration and inferior crystalline quality of top region of the ZnO layer suppressing the back channel, which can be confirmed from the XRD spectra of ZnO according to the film thickness shown in Fig. 3. The XRD peak at 34.1 representing the (002) ZnO crystal plane is observed. The grain sizes of the ZnO films with thicknesses of 40 and 100 nm are extracted using Scherrer’s formula as 15.4 and 19.8 nm, respectively. This V_{th} tendency is also applied to the U-shape structure with 40nm active thickness. As shown in Fig. 2, however, the electrical charateristics of U-shape device are much more improved than the standard 40 nm ZnO TFT. This is because U-shape structure has much thicker ZnO active layer near the source/drain (S/D) region and superior contact resistance characteristics. Fig. 4 shows that the contact resistances of TFTs as function of various ZnO active structures: 40 nm ZnO, 100 nm ZnO and U-shape. The contact resistances are extracted by R_{on}W-channel length curve. Fig. 5 shows I_{DS}-V_{GS} of the U-shape ZnO TFTs with negative bias stress (NBS). NBS stability is important considering that the switching TFT of AMOLED display is most of the time under a negative gate bias in its off state [6]. The result shows that the transfer curve shifts only -0.18 V after stress during 10^4 sec in the U-shape ZnO TFT. As mentioned before, the body metal contact structure can also control the device parameters but is weak in high temperature operation. Fig. 6 shows that transfer characteristics of U-shape and conventional 100 nm ZnO TFT with Au body metal after thermal stress of 150 °C. The temperature dependence of ZnO-based TFT is about -14.4 ~ -18 mV/°C. The V_{th} shift of U-shape structure is -1.73 V after thermal stress. It is within the general temperature dependence. However, in case of device with body metal, V_{th} shift is -3.04 V, which shows the U-shape structure is more stable in high temperature operation. For more aggressive application, the body metal effect is examined in the U-shape as shown in Fig. 7. As for the Au body metal contact whose work function is higher than ZnO, V_{th} shifts to positive direction because the Au depletes the ZnO body and the back channel formation is suppressed. The red solid symbol shows the body metal structure can be also applicable to U-shape structure. The extracted parameters are given in Table I.

4. Conclusions

In summary, we propose a ZnO TFT with U-shape active layer for the device performance enhancement including V_{th} modulation. U-shape structure can control V_{th} based on the thickness effect of active layer without contact resistance deterioration. The fabricated device shows better electrical properties than standard bottom gate ZnO TFT. Moreover, the U-shape structure is stable in high temperature operation, unlike the back metal contact structure. The experimental results show that the body metal structure can be also merged to U-shape structure for the more aggressive application.

Acknowledgements

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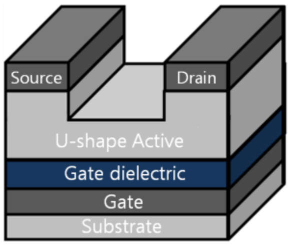

Fig. 1. Cross section of the suggested bottom gated U-shape ZnO TFT which is proposed to modulate Vth based on the thickness control of active layer without contact resistance deterioration. The channel width/length (W/L) is 2000/500 μm.

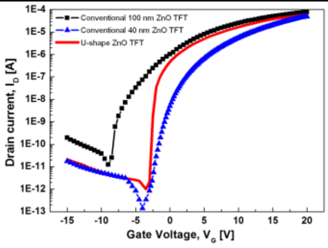

Fig. 2. Transfer characteristics of the fabricated ZnO TFTs as a function of the device structures: black square symbol is for the conventional TFT with 100 nm ZnO thickness, blue symbol for 40 nm ZnO and red line for U-shape. Here, V_{DS} is 20 V.

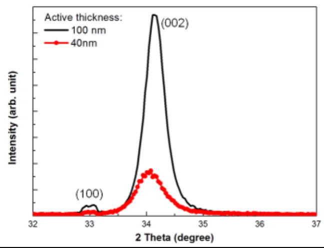

Fig. 3. XRD spectra of ZnO films according to the film thickness. The XRD peak at 34.1 represents the (002) ZnO crystal plane.

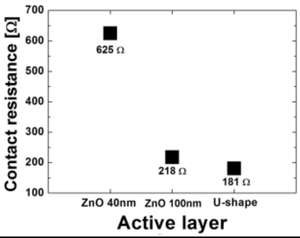

Fig. 4. Width normalized total resistance RonW versus physical channel length for the devices,

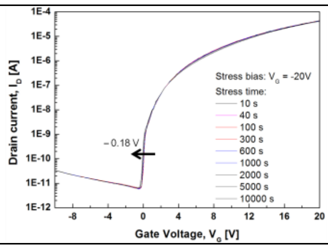

Fig. 5. Transfer characteristics of the U-shape ZnO TFTs with gate bias stress of -20 V which shows that the transfer curve shifts only -0.18 V after stress during 10^4 sec in the U-shape ZnO TFT. The applied V_{DS} is 20 V.

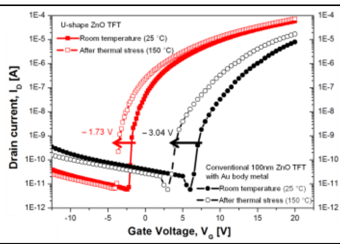

Fig. 6. Transfer characteristics of U-shape structure and conventional 100 nm ZnO with Au body metal TFT. Dash lines are thermal stress after 30 minutes at 150 ℃.

Table 1. Electrical characteristics of ZnO TFT as function of various structures and Au body metal contact. All of the electrical properties are measured at room temperature using Agilent 4155B semiconductor parameter analyzer.

Active structure	Au body metal	Vth [V]	μ_{sat} [cm/V·s]	SS [dec/V]	On/off current ratio
Conventional 40 nm	X	-1.5	0.95	0.93	5.91×10^7
Conventional 100 nm	X	-8.2	2.41	0.20	6.18×10^6
	O	6.6	0.80	0.22	1.36×10^6
U-shape	X	-2.4	2.17	0.14	3.48×10^8
	O	17.1	0.44	0.46	9.89×10^6

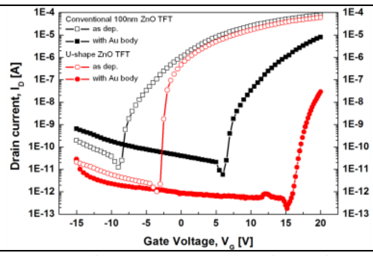

Fig. 7. Transfer characteristics of the fabricated ZnO TFTs with Au body metal contact: black symbols for conventional 100 nm ZnO TFTs and red symbols for U-shape ZnO TFTs. The solid symbols are for U-shape devices with Au body. metal contact.