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Zinc Oxide Thin-Film Transistors on Flexible Plastic Substrates and Glass Substrates Fabricated at Room Temperature

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1. Introduction

Oxide semiconductor has attracted attention as one of the key materials for the realization of transparent flexible electronic devices. Especially, oxide semiconductors such as amorphous indium gallium zinc oxide (a-IGZO) based thin-film transistors (TFTs) are being researched by many groups since they have higher electron mobility than that of other flexible materials such as organic semiconductors and hydrogenated amorphous silicon (a-Si:H).

TFTs with a-IGZO channel layers fabricated on unheated glass or organic-film substrates have been reported so far [1-3]. The a-IGZO based TFT demonstrated with high performance and stability, ZnO based TFT has more environmental acceptability than that of a-IGZO, because an indium in a-IGZO is a relatively scarce element in the earth's crust. Tin-doped indium oxide (ITO) is also the most successful a transparent conductive oxide.

In addition, an indium-free zinc oxide (ZnO) semiconductor is also well recognized as an ecological and economical semiconductor, and it has the greatest potential to grow high quality crystalline at low temperature. This is particularly advantageous for new functional flexible devices [4,5].

In this paper, we report the fabrication and characterization on high-performance ZnO based TFTs on unheated glass and polyethylene napthalate (PEN) substrate by pulsed laser deposition.

2. Fabrication Process and Device Structure

ZnO films were grown by pulsed laser deposition (PLD) on a Corning #1737 glass substrate and plastic PEN substrate. A Nd:YAG laser (4th harmonic, 266 nm) was used for ablation of the ZnO ceramic target. The laser repetition rate was 10 Hz, the laser pulse energy density was 2-3 J/cm^2. ZnO films were deposited at room temperature in the oxygen partial pressure, PO_2 of 2×10^{-4} Torr. The total thicknesses of ZnO were 40 nm.

Then, top-gate ZnO-TFTs were fabricated by photolithography and wet chemical etching. The source and drain contacts were formed by lift-off of e-beam deposited Ti (20 nm) / Au (200 nm). An HfO_2 with thickness 100 nm was selected as the gate insulator, and top gate electrode Ti (20 nm) / Au (200 nm) was deposited by e-beam evaporation.

3. Results and Discussion

Drain current (I_D) – drain voltage (V_{DS}) characteristics of the fabricated ZnO TFTs on PEN substrate (Structure B) for the different devices are shown in Fig. 2.

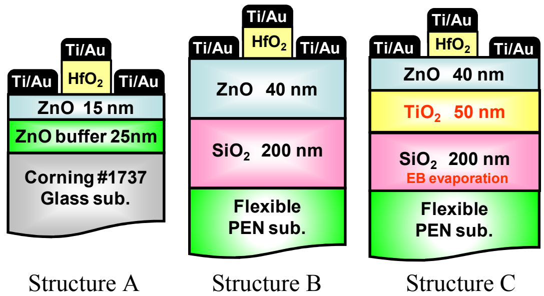


Fig. 1 Schematic diagrams of fabricated ZnO-TFTs on glass and PEN substrate. ZnO channel layer are grown on (a) a 25 nm ZnO buffer layer on a glass substrate, (b) with a SiO_2 buffer layer on a PEN, (c) with a SiO_2/TiO_2 buffer on a PEN, respectively.

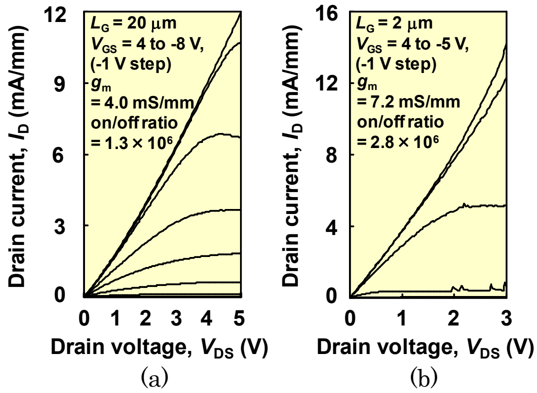
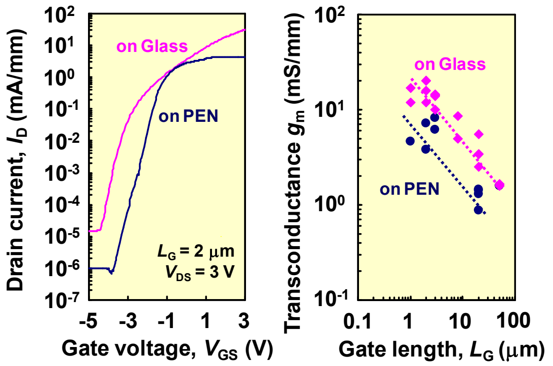


Fig. 2 I_D-V_{DS} characteristics of the fabricated ZnO-TFTs (a) with 20 μm-gate-length, (b) with 2 μm-gate-length, respectively.

The gate lengths (L_G) are 20 μm and 2 μm, respectively. The channel width (W) is 50 μm. The both TFTs showed n-channel depletion mode characteristics. The 20 μm-gate-length TFT had on/off current ratio of 1.3×10^6, the maximum transconductance, g_m of 4.0 mS/mm, threshold voltage, V_{TH} of -4.30 V and sub-threshold-swing, *S.S.* values of 0.35 V/decade were obtained. On the other hand, a TFT with gate length of 2 μm had higher on/off current ratio of 2.8×10^6, g_m of 7.2 mS/mm, V_{TH} of -2.90 V and *S.S.* values of 0.28 V/decade were obtained. From the results for the different devices of the ZnO-TFTs on glass substrates (Structure A) and PEN substrate (Structure B), the on/off ratio and the g_m were compared. The similar high on/off current ratio of 10^6 was obtained. The maximum g_m values for the TFT on glass substrates were always slightly higher than that of the TFT on the PEN substrates. In addition, the higher g_m values than 1 mS/mm were obtained for the TFTs on PEN of the gate length less than 20 μm.



(a) (b)

Fig. 3 Comparison of on/off ratio and g_m in ZnO-TFT between on glass substrate with on PEN substrate. (a) On/off ratio, (b) transconductance, g_m.

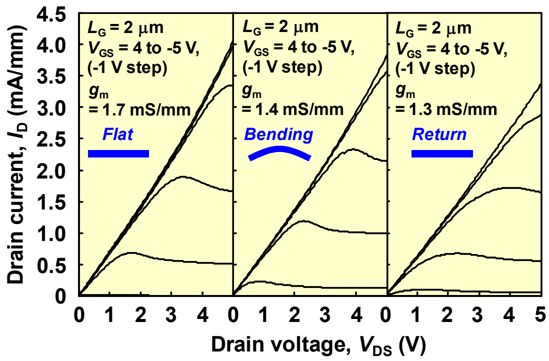
Next, 40 nm ZnO film and 50 nm TiO_2 buffer layer were grown on PEN substrate with SiO_2 buffer layer by PLD continuously (Structure C in Fig. 1). Because the TiO_2 buffer layer provides better adhesion to the ZnO than SiO_2, depositing the ZnO film by PLD without breaking the vacuum might be expected to improve the properties of the resulting thin films. We prepared a set of the structure with SiO_2/TiO_2 to investigate the characteristic changes that appear in the film characteristics in response to bending.

Figure 4 (a) shows the I_D-V_{DS} and the transfer characteristics, which are affected by bending and return for the ZnO-TFT with SiO_2/TiO_2 buffers. The TFTs were bent to a curvature radius of 8.5 mm. The transconductance, g_m are obtained 1.7 mS/mm on flat, 1.4 mS/mm on bending and 1.3 mS/mm on returning the film, respectively. The I_D-V_{DS} characteristics were therefore not changed drastically by bending. Figure 4 (b) shows the source-to-drain current as a function of gate voltage (V_{GS}) at a fixed drain voltage of 4.0 V for films made before, during, and after bending. All of the devices exhibited a clear pinch-off behavior and a high on/off current ratio of ~10^6. The threshold voltage, V_{th} was not changed drastically.

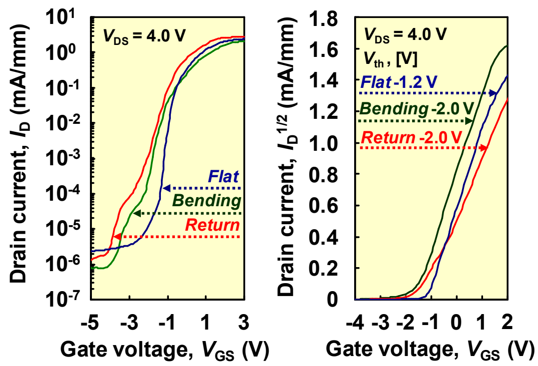
Figure 5 shows the relationship the g_m and the L_g characteristics of ZnO-TFTs on PEN compared the flat and bending state. The values of the g_m were increased with decreasing the gate length. In the range less than 10 μm, the g_m of the TFT on bending is comparable with that of flat state. These results show that this approach might pave the way for the realization of future electric applications such as ZnO transparent flexible electronics.

4. Conclusion

ZnO-TFTs were fabricated by PLD on glass and PEN substrates at room temperature. ZnO-TFTs on PEN substrate were fabricated by using SiO_2/TiO_2 buffer layer, the g_m of 1.7 mS/mm, an on/off ratio 10^6 were obtained. The ZnO-TFTs were bent at curvature radius of 8.5 mm, and the operation characteristics were not changed significantly.



(a)



(b) (c)

Fig. 4 (a) I_D-V_{DS} characteristics of the fabricated ZnO-TFTs on a flexible PEN substrate by the different conditions (flat, bending, and return). (b) Transfer characteristics and (c) threshold voltage, V_{TH} of the fabricated ZnO-TFTs on PEN.

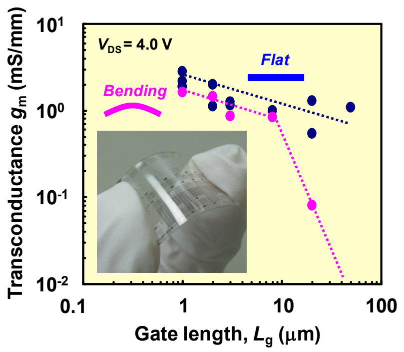


Fig. 5 The g_m-L_G characteristics of ZnO-TFTs on PEN compared the flat state and bending state.

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