Positive Bias-Stress Stability of Flexible Amorphous InGaZnO Thin Film Transistors with Double-Stacked Gate Insulators

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ABSTRACT

Double-stacked gate insulators (SiO_x/TaO_x) made flexible amorphous InGaZnO thin film transistors more stable under both mechanical bending and positive bias-stress, which was assumed to result from their better neutral plane position and front-channel interface states. A simple model was built to explain this improvement effect.

1 INTRODUCTION

Amorphous InGaZnO thin film transistors (a-IGZO TFTs) have been extensively investigated to address flexible displays [1,2]. However, flexible a-IGZO TFTs would degrade or even suffer from cracking if the improper gate insulators were adopted [3,4]. Therefore, development of better gate insulators for flexible a-IGZO TFTs becomes necessary. Recently, we proposed a double-stacked gate insulator (DSGI), i.e., SiOx/TaOx, which made flexible a-IGZO TFTs more stable after bending treatments [5]. Compared with single-layer gate insulators (SLGI), DSGI led to better stability of the devices after being bent to 5 mm and flatted [5]. In this study, we further investigated the positive bias-stress (PBS) stability of flexible a-IGZO TFTs with SLGI or DSGI under mechanical bending. The DSCL devices exhibited more stable properties, which was assumed to be due to the improvement of the neutral plane position and the front-channel interfaces in the flexible a-IGZO TFTs.

2 EXPERIMENT

Fig. 1(a) shows the inverted-staggered TFT device structure used in this study. Both SLGI (600-nm-thick sputtered SiO_x) and DSGI (Sputtered 300-nm-thick SiO_x/300-nm-thick TaO_x) were employed here. First, the 20-μm-thick PI films were attached to the 500-μm-thick glass substrates by PDMS. Then, the buffer layers (600-nm-thick SiO_x), gate electrodes (100-nm-thick indium tin oxide (ITO)), and gate insulators (600-nm-thick SLGI or DSGI) were deposited by RF sputtering. Next, the 50-nm-thick a-IGZO films were prepared as the channel layers by RF magnetron sputtering, using an alloy target (In:Ga:Zn:O=1:1:1:4). During the depositions of the a-IGZO films, the RF power, chamber pressure, Ar flow rate, and O_2 flow rate were fixed as 80 W, 3 mTorr, 30 sccm, and 1 sccm, respectively. The ITO films were deposited as the source/drain (S/D) electrodes by DC magnetron sputtering. Both the channel layers and the S/D electrodes were patterned by shadow masks during their depositions. Finally, the TFT devices were annealed in air at 683 K for 1 h to improve their electrical properties.

The electrical measurements were performed by a semiconductor analyzer (Keithley 4200) in the dark. In addition to the measurements of TFT transfer curves, the being-bent-tests of flexible a-IGZO TFTs were also employed, as shown in Fig. 1(b). Compared with our previous study in Ref. [5], the being-bent-tests should be severer than the measurements after being bent and flatted. What's more, the samples prepared in this study were rather large (W/L=1000 μm/275 μm), which made the devices quite sensitive to the bending treatments [6]. Threshold voltage (V_{TH}) values were extracted from the transfer curves at $I_{DS}=10^{-7}$A/(W/L).

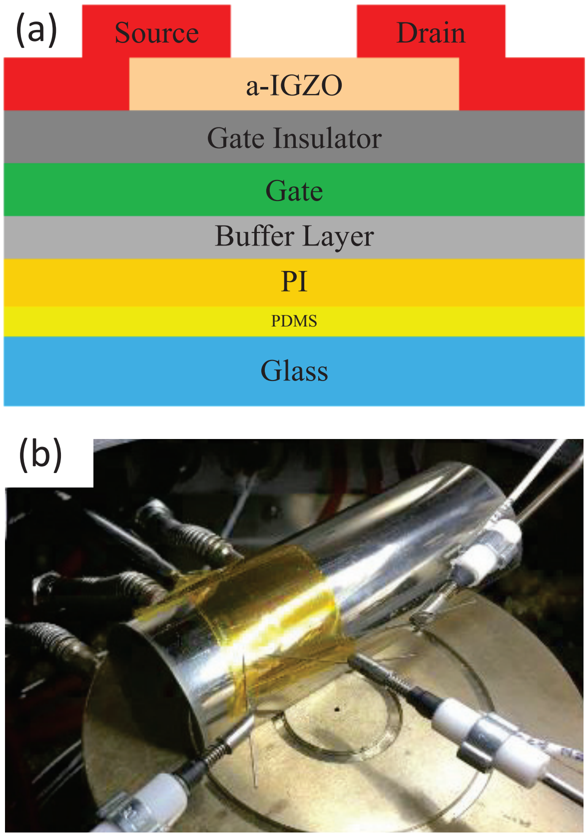

Fig. 1 (a) Schematic cross-section of the flexible a-IGZO TFTs in this study. (b) Electrical measurements of the flexible a-IGZO TFTs at various bending radii.

3 RESULTS

For the flexible a-IGZO TFTs with SLGI, as shown in Fig. 2(a), their transfer curves degraded seriously with the bending radius (R) decreasing. One may observe that the transfer curve of the a-IGZO TFTs shifted negatively with the increase in the mechanical bending. Especially, the off-current of the devices increased apparently under bending conditions, which resulted from the rise in the gate leakage current (I_{GS}), as shown in the inset of Fig. 2(a). On the contrary, the devices with DSGI showed more stable transfer properties when they were applied by mechanical bending, as shown in Fig. 2(b). This result was assumed to be related to their more stable gate leakage currents. As shown in the insets of Fig. 2(b), the I_{GS} of DSGI was more prone to the bending treatments than SLGI.

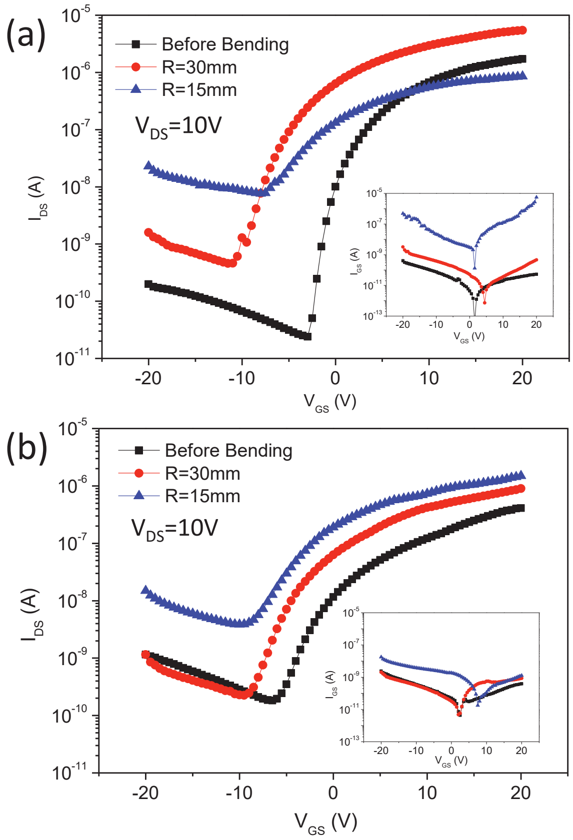

Fig. 2 Transfer curves of flexible a-IGZO TFTs with (a) SLGI and (b) DSGI under various bending conditions; inset: influence of bending treatments on gate leakage currents.

For the actual applications of flexible a-IGZO TFTs, the bias-stress and bending treatments could be applied simultaneously. Therefore, investigating the instability of flexible TFT devices under both bias-stress and bending should be meaningful. Accordingly, we performed the PBS tests of flexible a-IGZO TFTs under bending of R=30 mm. For the PBS tests, the bias-stress voltage of +20 V was applied in this study. Since there were no passivation layers for the TFT samples in this study, the flexible a-IGZO TFTs exhibited quite unstable properties during PBS tests, as shown in Figs 3 and 4.

For the SLGI-devices, as shown in Fig. 3(a), their transfer curve shifted positively with the stress time increasing. The instability of a-IGZO TFTs during PBS tests resulted from both charge trapping at their front-channel interfaces and ambient effect at their back-channel interfaces [7,8]. When both bias-stress and bending were applied to the SLGI-devices, as shown in Fig. 3(b), the flexible a-IGZO TFTs became more unstable. One should notice that the initial curve of the being-bent-device during PBS tests (as shown in Fig. 3(a)) was quite different from that of the before-bending device (as shown in Fig. 3(b)). More importantly, the much larger shifts of the transfer curves could be observed for the being-bent-devices.

For the DSGI devices, however, the difference between the PBS instability of the before-bending-devices (as shown in Fig. 4(a)) and that of the being-bent-devices (as shown in Fig. 4(b)) was rather small. In other words, the DSGI made flexible a-IGZO TFTs more prone to the combinational influence of mechanical bending and bias-stress treatments.

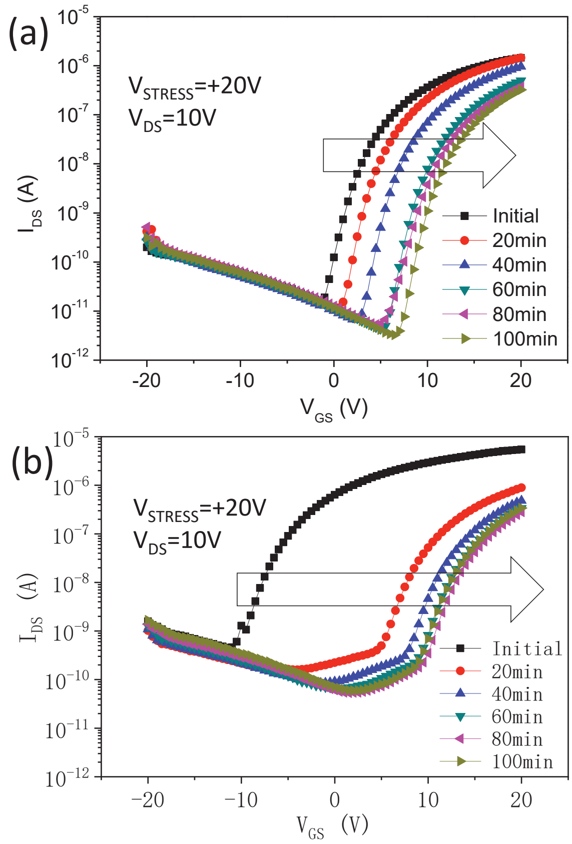

Fig. 3 PBS testing results of the flexible a-IGZO TFTs with SLGI (a) before bending and (b) under bending radius of R=30 mm.

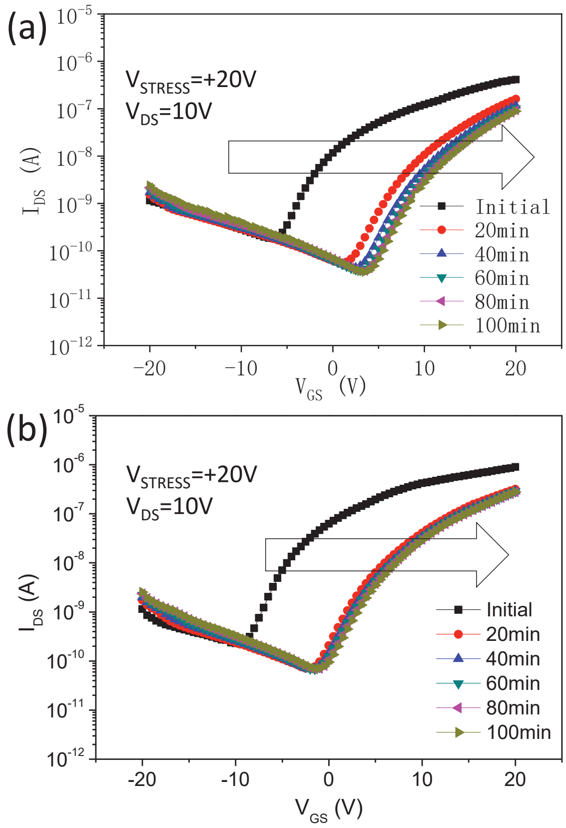

Fig. 4 PBS testing results of the flexible a-IGZO TFTs with DSGI (a) before bending and (b) under bending radius of R=30 mm.

To quantitatively investigate the influence of the mechanical bending on the PBS instability of flexible a-IGZO TFTs, we extracted the V_{TH} values of the devices at different stress time and bending states from the experimental data in Figs 3 and 4. Then, a very useful term, threshold voltage shift (ΔV_{TH}), could be calculated as follows:

$$\Delta V_{TH} = V_{TH}(Stress - time) - V_{TH}(Initial) \qquad (1)$$

Fig. 5 shows the stress time dependence of ΔV_{TH} for the flexible a-IGZO TFTs with SLGI and DSGI. The ΔV_{TH} gradually increased with the stress time increasing. However, the mechanical bending (R=30 mm) resulted in larger ΔV_{TH} for the same stress time. The gap between the curve of the before-bending-device and that of the being-bent-device can represent the sensitivity of PBS stability to the mechanical bending. Apparently, the smaller this gap is, the less sensitive the PBS stability should be to the bending treatment.

As shown in Fig. 5(a), the mechanical bending led to a big jump of ΔV_{TH} for the device with SLGI. Contrarily, the ΔV_{TH}-Stress time curve of the flexible a-IGZO TFTs with DSGI exhibited a very small change between the before-bending-device and the being-bent device, as shown in Fig. 5(b). In other words, the DSGI made the flexible a-IGZO TFTs more prone to the mechanical bending during their PBS tests.

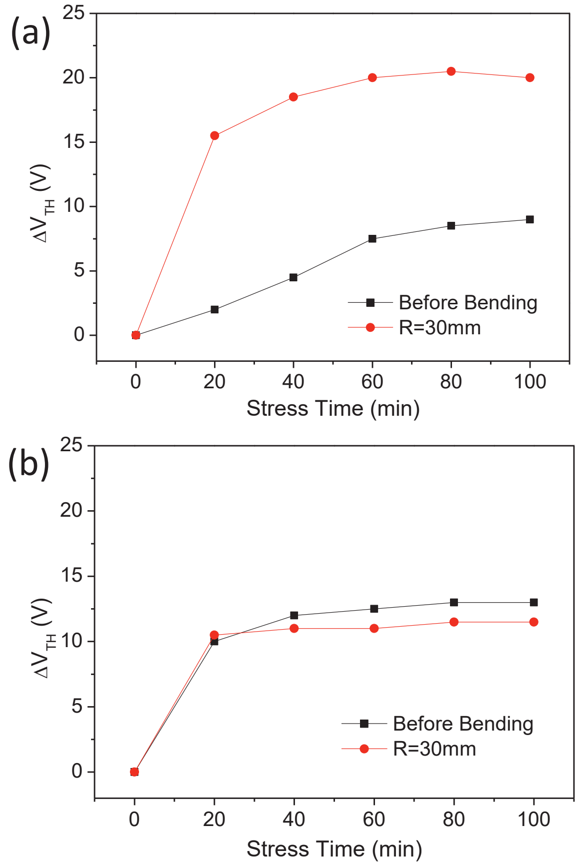

Fig. 5 Dependence of threshold voltage shift on stress time for PBS tests of flexible a-IGZO TFTs with (a) SLGI and (b) DSGI.

4 DISCUSSION

So far, an important result has been obtained in this study: DSGI could effectively improve the bending stability of flexible a-IGZO TFTs during their PBS tests. But why?

Firstly, the stability improvement of flexible a-IGZO TFTs with DSGI was assumed to be related to the neutral plane position change due to the large Youg' s Modulus of TaOx (~186 MPa). The neutral plane is the position where the internal stress equals zero. The stress becomes smaller at the position nearer to the neutral plane. Position of the neutral plane is estimated using the following formula [9]:

$$z_n = \frac{1}{2}\frac{\sum_1^n E_i(z_i^2 - z_{i-1}^2)}{\sum_1^n E_i(z_i - z_{i-1})} \qquad (2)$$

where E_i and z_i are the effective Young's modulus and the position of the i_{th} layer from the bottom of the tape, respectively. Since the Young's modulus of TaO_x (~186 MPa) is much larger than that of SiO_x (~70 GPa), the neutral plane position in the samples with DSGI should be closer to the TFTs than that in the samples with SLGI. As shown in Fig. 6, the neutral plane of the DSGI device became nearer to the TFTs. Accordingly, the flexible a-IGZO TFTs suffered from smaller stress (strain) when they were bent, and then their PBS stability showed a smaller change under the mechanical bending.

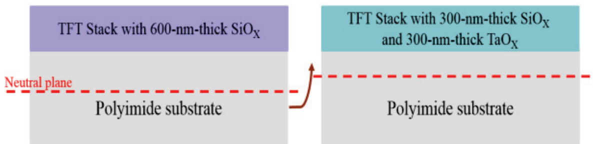

Fig. 6 Schematics of neutral plane positions of the flexible a-IGZO TFTs with (a) SLGI and (b) DSGI.

In addition, the surface roughness of DSGI was smaller than that of SLGI [5], which might result in better interface states between GI and a-IGZO. We assumed that there exited less trap states at the front channel interfaces of the DSGI-devices, leading to smaller variations in threshold voltage shifts under bending during PBS tests.

5 CONCLUSIONS

The flexible a-IGZO TFTs with double-stacked gate insulators (SiO_x/TaO_x) were proved to be more stable under both mechanical bending and bias-stress, the physical mechanism of which was in-depth discussed. Both proper neutral plane position and better front interface states were assumed to be responsible for this improvement effect. We believe that the DSGI can be used in mass productions of flexible a-IGZO TFTs.

6 ACKNOWLEDGEMENT

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REFERENCES

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, H. Hosono, Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors, Nature, Vol. 432, pp. 488-492 (2004).
[2] J. Park, T. Kim, D. Stryakhilev, J. Lee, S. An, Y. Pyo, D. Lee, Y. G. Mo, D. Jin, H. K. Chung, Flexible full color organic light-emitting diode display on polyimide plastic substrate driven by amorphous indium gallium zinc oxide thin-film transistors, Appl. Phys. Lett., Vol. 95, pp. 013503 (2009).
[3] K. H. Cherenack, N. S. Munzenrieder, G. Troster, Impact of mechanical bending on ZnO and IGZO thin-film transistors, IEEE Electron Devi. Lett., Vol. 31, pp. 1254-1256 (2010).
[4] M. H. Lee, S. M. Hsu, J. D. Shen, C. Liu, Stress distribution of IGZO TFTs under mechanical rolling using finite element method for flexible applications, Microelectronic Engineering, Vol. 138, pp. 77-80 (2015).
[5] C. Dong, G. Liu, Y. Zhang, G. Feng, and Y. Zhou, Double-stacked gate insulators SiOx/TaOx for flexible amorphous InGaZnO thin film transistors, Mater. Sci. Semicond. Process., Vol. 96, pp. 99-103 (2019).
[6] G. P. Crawford, Flexible Flat Panel Displays, John Wiley & Sons, Ltd, 2005.
[7] J. Xu, Q. Wu, L. Xu, H. Xie, G. Liu, L. Zhang, and C. Dong, Ambient effect on thermal stability of amorphous InGaZnO thin film transistors, Solid State Electron., Vol. 126, pp. 170–174 (2016).
[8] Y. Zhou, J. Xu, H. Xie, L. Zhang, G. Liu, X. Tong, and C. Dong, Moisture dominant electrical degradation of amorphous InGaZnO thin film transistors under positive bias stress, Proc. IDW'17, pp. 424-426 (2017)
[9] A. K. Tripathi, K. Myny, B. Hou, K. Wezenberg, G. H. Gelinck, Electrical characterization of flexible InGaZnO transistors and 8-b transponder chip down to a bending radius of 2 mm, IEEE Trans. Electron Devi., Vol. 62, pp. 4063-068 (2015).