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Understanding the Role of Temperature and Drain Current Stress in InSnZnO TFTs with Various Active Layer Thicknesses

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Abstract: Thin-film transistor (TFT) devices composed of metal oxide semiconductors have attracted tremendous research attention globally in recent years. Owing to their ability to offer mobility, metal oxide semiconductor materials can enable high-performance TFTs for next-generation integrated display devices. Nevertheless, further breakthroughs of metal oxide TFTs are mainly obstructed by their long-term variability, the reason for which is not yet fully understood. Herein, TFTs based on InSnZnO (ITZO) with various thicknesses (T_{ITZO}) were prepared and their long-term stabilities under test temperatures and drain current stress were investigated. The results indicate that ITZO TFTs exhibit outstanding electrical properties regardless of the T_{ITZO} , including a high saturated mobility of over $35 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ and sharp subthreshold swing. Note that the transfer and output characteristic curves of the device with a thick T_{ITZO} of 100 nm express an abnormal current surge when high gate and drain voltages are exerted, which is attributed to the floating body effect, caused when the imposed electric field induces impact ionization near the drain side. More interestingly, these drain current stress results further suggest that the abnormal shift behavior of the electrical properties of the ITZO TFTs with a T_{ITZO} of greater than 75 nm is observed to deteriorate gradually with increasing temperature and drain current bias. This study addresses that such a degradation effect should be restrained for the operation of high-mobility devices.

Keywords: drain current bias; test temperature; InSnZnO; TFT device; channel layer thickness

1. Introduction

Metal oxide semiconductors have recently emerged as extremely sought-after materials for thin-film transistor (TFT) applications [1–6]. Over the past decade, the mobility (μ) of TFTs employing these semiconductors, such as InGaZnO, has greatly increased, and is comparable to that of polysilicon-based devices [7]. These metal oxide semiconductors also possess promise for various optoelectronic applications, including photodetectors and solar cells [8–11]. Inspired by the achievement of metal oxide films, another category of these materials, called InSnZnO (ITZO), was studied by our group in 2012 [12]. From the perspective of potential applications in flat panel displays

(FPDs), the ITZO TFTs have been gifted with desirable electrical properties, especially the high μ of $>30 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$, which originates from the 5 s orbital overlaps of In and Sn atoms [13].

Besides the tremendous developments of metal oxide semiconductors and TFT structures, an intensive understanding of the charge-carrier transport processes is beneficial to further improving the TFT characteristics. In addition, the systematic carrier motion model extending to the internal active layer, which is the core of operating TFT devices, still needs to be studied. Adjusting the metal oxide thickness is an intuitive and effective parameter of the model to investigate the charge transport processes in the bulk of the active layer with [14–16], while leaving the condition of the adjacent interfaces almost unchanged. Apart from the design and fabrication of TFT architectures, the measurement approach is also a crucial step to set up the fundamental physical framework [17]. In addition, in terms of TFT devices, the long-term stabilities are critical to drive TFT-contained integrated circuits in FPDs [18,19]. Moreover, the drain current stress is a common working procedure in current-biased TFTs [20].

In this regard, here the typical TFT device structure is considered to verify the universality of the overall framework. On the basis of the device's architecture, channel layers with different thicknesses (T_{ITZO}) are then designed. To evaluate the device's stability, the measurement conditions and working environment are taken into consideration. More importantly, to understand the carrier transport mechanism in the devices, both the channel layer thickness and drain current stress (DCS) should be fully considered.

2. Experimental

Figure 1 displays the device architecture and fabrication procedure of ITZO-based TFT, which refers to our previous publication [21]. The chromium gate electrode was prepared on the glass substrate, and the SiO_x gate insulator with a thickness of 150 nm was formed by plasma-enhanced chemical vapor deposition (PECVD). For the active layers, ITZO films with the thicknesses of 45, 75, and 100 nm were prepared by DC magnetron sputtering with a mixed gas of $\text{Ar}/\text{O}_2 = 15/15 \text{ sccm}$ at a deposition pressure of 1 Pa. Then, a 200 nm thick SiO_x etch-stopper was deposited by PECVD, and indium-tin-oxide source and drain electrodes were formed. Finally, a SiO_x passivation layer was fabricated by PECVD. After the fabrication of devices with channel widths of $50 \mu\text{m}$ and lengths of $20 \mu\text{m}$, the TFTs were post-treated in a nitrogen atmosphere at 350°C for 1 h. All the current–voltage (I–V) results were evaluated by an Agilent 4156C precision semiconductor parameter analyzer in air.

Figure 1. Device architecture and preparation process of the ITZO TFT.

3. Results and Discussion

The transfer curves of TFT devices with different T_{ITZO} were evaluated at a drain voltage (V_{DS}) of 0.1 and 20.1 V, as shown in Figure 2. The linear (μ_{lin}) and saturated (μ_{sat}) mobilities were estimated on the basis of previous literature [21]. The turn-on voltage (V_{ON}) was extracted from the gate voltage (V_{GS}) at a drain current (I_{DS}) of 1 nA. The hysteresis (ΔV_{H}) was calculated from the V_{ON} difference value between the forward and reverse scans of the transfer curves. The subthreshold swing (SS) was defined to be $dV_{\text{GS}}/d\log_{10}(I_{\text{DS}})$. The respective parameters were extracted from the forward sweep, as tabulated in Table 1.

Figure 2. Transfer characteristics of TFT devices with different T_{ITZO} of (a) 45, (b) 75, and (c) 100 nm evaluated at a V_{DS} of 0.1 and 20.1 V.

Table 1. The electrical parameters of a-ITZO TFTs with various T_{ITZO} extracted from the forward sweep.

Thickness (nm)	45	75	100
μ_{lin} ($\text{cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$)	28.76	33.27	46.36
μ_{sat} ($\text{cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$)	35.23	46.90	130.10
V_{ON} at $I_{DS} = 1$ nA (V)	1.19	0.43	−0.33
Hysteresis ΔV_H (V)	0.22	0.07	−6.38
Subthreshold swing (mV/dec.)	169	130	88

For the device with a 45 nm T_{ITZO} , a μ_{lin} of $28.76 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$, μ_{sat} of $35.23 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}$, V_{ON} of 1.19 V, ΔV_H of 0.22 V, and SS of 169 mV/dec. were calculated. The observed results indicate that ITZO-based TFTs exhibit outstanding electrical characteristics which are generally superior to the results of IGZO-based TFT devices [22]. The μ_{lin} gradually rose to 33.27 and $46.36 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$ when the T_{ITZO} thickened to 75 and 100 nm, respectively. For the mobility extracted from the saturation region, the μ_{sat} significantly increased to $46.90 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$ for the 75 nm T_{ITZO} device, and sharply soared to $130.10 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$ as the T_{ITZO} further thickened to 100 nm. It was found that the I_{DS} values significantly increased with the increase in T_{ITZO} . In general, the increase in the μ and I_{DS} of the thicker channel TFT was attributed to the increase in carrier concentration and decrease in the density of subgap states, which were based on the percolation conduction and multiple trapping and release model [23,24]. Combined with the transfer curves observed from the 100 nm T_{ITZO} TFT measured with a V_{DS} of 20.1 V and V_{GS} of ~ 20 V, we can conclude that the calculated μ_{sat} hardly represents the intrinsic properties of the ITZO material. In the sections of DCS-induced instabilities, for the devices with thicker T_{ITZO} TFT and measurement modes with a high V_{DS} and V_{GS} bias, this conclusion of the sudden increase in the μ_{sat} was further confirmed. In addition, the V_{ON} slightly shifted to 0.43 and -0.33 V as the T_{ITZO} gradually thickened to 75 and 100 nm, respectively. Because the free carrier content in the bulk is directly proportional to the thickness of samples [25], the V_{ON} changed in the negative V_{GS} direction with the increase in the T_{ITZO} . The negligible clockwise hysteresis was observed for the devices with a T_{ITZO} of 45 and 75 nm. As the T_{ITZO} was enlarged to 100 nm, an abnormal

anticlockwise hysteresis of -6.38 V was obtained. In other words, the V_{GS} was swept forward from -10 to 20 V with 20.1 V V_{DS} .

On the basis of the previous publication [26], high- μ TFTs experiencing drain current stress may induce the floating body effect that impacts ionization, producing electron-hole pairs in the drain side. The generated holes drift to the ITZO/etch-stopper interface due to the longitudinal electric field and flow to the source region due to the transverse electric field. Furthermore, for the TFTs with a thick T_{ITZO} , superfluous holes are trapped in the source area of the back-channel interface, naturally causing the transfer curve's negative shift. Therefore, in terms of 100-nm-thick ITZO TFTs, a tremendous shift in the negative V_{GS} direction was observed in the transfer properties, leading to the great hysteresis. Interestingly, the SS values manifest the gradient descent as 130 and 88 mV/dec. as the T_{ITZO} increases to 75 and 100 nm, respectively. This behavior is due to the fact that the densities of interface traps at the ITZO/etch-stopper area are lessened as the T_{ITZO} increases [27]. It is commonly known that the SS is the direct parameter by which to evaluate the integration of trap state densities in the ITZO film and corresponding interfaces [28]. The results further imply that the interface quality is directly related to the device properties.

Figure 3 plots the typical output curves of ITZO TFTs with various T_{ITZO} . The V_{GS} was altered from 5 to 20 V in increments of 5 V. All devices exhibited standard n-type field-effect transistor behavior. When the TFTs were switched on, the output properties presented enhancement-mode operation with a clear pinch-off phenomenon regardless of the T_{ITZO} . For the devices based on 45 and 75 nm T_{ITZO} , the current saturation response was evidently observed. The saturation current under the identical V_{GS} and V_{DS} biases gradually increased with the T_{ITZO} . For 100 nm T_{ITZO} TFT, a similar current saturation response was also obtained when the V_{GS} was controlled below 15 V. However, the output characteristics expressed a current increase under high drain and source voltages of 20 V. This phenomenon can be explained by the kink effect that impacts ionization-induced hole flow towards the source side. Moreover, electrons were injected into the channel from the source side and collected at the drain region. The extra drain current accelerated the impact ionization probability. Consequently, this effect led to a sharp rise in the output characteristics, which was in agreement with the results for the transfer characteristics.

Figure 3. Output characteristics of TFT devices with various T_{ITZO} of (a) 45, (b) 75, and (c) 100 nm.

To comprehend the influence of measurement temperatures on the DCS-induced instability of ITZO TFTs with various T_{ITZO} , the test platform temperatures were set to 25, 50, 75, and 100 °C, and the DCS of $V_{GS} = V_{DS} = 10$ V was fixed for 10^4 s. To avoid the abnormal transfer curve shift occurring, a V_{DS} of 10.1 V was chosen. The variations in the transfer properties of ITZO TFTs with different T_{ITZO} were studied under DCS at various test temperatures (Figure 4). Correspondingly, the changes in V_{ON} (ΔV_{ON}) accompanied by DCS time under various test temperatures are shown in Figure 5. It is noted that the current fluctuations in the OFF-current region are observed in some I-V curves. This phenomenon may be due to the poor shielding effect of the test platform during the measurement process. Even so, a current level of below 10^{-13} A had no effect on the DCS evaluation. For the devices measured at room temperature, all of the transfer curves exhibited stable behaviors even throughout a long-term duration, suggesting that a high quality GI layer has been fabricated, and the electrons were

seldom captured at the ITZO/GI interface. As the test temperature was raised to 50 °C, the electrical properties of 45 and 75 nm T_{ITZO} TFTs still presented a steady state. However, in terms of the device with a thick T_{ITZO} of 100 nm, a parallel shift in the transfer characteristics with a ΔV_{ON} of -1.60 V was observed after the DCS duration. The results indicate that a high temperature promotes thermal movement of the electron, contributing to the occurrence probability of impact ionization. As the temperature was further adjusted to 75 °C, the transfer curves of the TFT with 45 nm T_{ITZO} shifted by 1.02 V towards a positive V_{GS} direction with unchanged SS during the 10^4 s stress time, demonstrating that the generated electrons induced by thermal activation were trapped at the front interface. It was noted that the device with a 75 nm T_{ITZO} still maintained excellent electrical stability. In the case of the 100 nm T_{ITZO} device, the motion behavior was enlarged and the ΔV_{ON} was aggravated to -1.85 V. When the platform temperature was increased to a harsh condition of 100 °C, the transfer curves of the TFT with a 45 nm T_{ITZO} continually changed by 1.40 V after the DCS duration. In contrast, for the T_{ITZO} thicknesses of 75 and 100 nm, the transfer characteristics showed parallel movement in a negative way and the ΔV_{ON} values were respectively exacerbated to -1.27 and -3.18 V over the whole DCS time. These results state that temperature plays a key role in exciting electron movement, thereby concretizing and enlarging electron-related effects.

Figure 4. Evolution of transfer characteristics as a function of DCS ($V_{GS} = V_{DS} = 10$ V) duration for 10^4 s for the devices with a T_{ITZO} of 45 nm measured at test temperatures of (a) 25, (b) 50, (c) 75, and (d) 100 °C; with a T_{ITZO} of 75 nm measured at test temperatures of (e) 25, (f) 50, (g) 75, and (h) 100 °C; and with a T_{ITZO} of 100 nm measured at test temperatures of (i) 25, (j) 50, (k) 75, and (l) 100 °C.

Figure 5. Variation in the ΔV_{ON} with DCS duration for the TFT devices measured at test temperatures of (a) RT, (b) 50, (c) 75, and (d) 100 °C.

To further study DCS-caused instability of the ITZO TFTs with various T_{ITZO} , the I_{DS} values of 10, 60, 120, and 180 μA adjusted by the gate and drain voltages ($V_{GS} = V_{DS}$) were applied at 50 °C up to the stress duration of 10^4 s. It should be noted that these I_{DS} values are much higher than those applied in conventional active-matrix organic light-emitting diodes displays ($\sim 2 \mu A$) [29]. Figure 6 displays the corresponding variation in the transfer curves of the devices. Note that the transfer characteristics of all TFTs under various I_{DS} stresses exhibit a parallel shift without SS degradation. The corresponding ΔV_{ON} fluctuations are plotted in Figure 7. All devices exhibit acceptable reliability under 10 μA DCS irrespective of the T_{ITZO} , implying that few electron trapping sites exist in the ITZO bulk and at the ITZO/GI interface. Interestingly, with the increase in the I_{DS} stress, a ΔV_{ON} with a significant T_{ITZO} dependence was observed. For the 45 nm T_{ITZO} TFT, the V_{ON} positively shifted with the increase in the I_{DS} stress. The positive shift behavior was enlarged by increasing the stress duration. For the 180 μA I_{DS} stress, the transfer curves parallel shifted by 1.21 V towards the positive V_{GS} direction under the stress duration of 3000 s. In the subsequent stress time, the ΔV_{ON} shift was saturated in a short stress time, and then slightly moved back to 1.10 V. In contrast, when the thickness increased to 75 and 100 nm, the transfer curves completely changed in the negative V_{GS} direction irrespective of the I_{DS} stress. Under the 180 μA I_{DS} stress, the ΔV_{ON} of the TFTs with T_{ITZO} of 75 and 100 nm decreased by -2.98 and -3.50 V, respectively. The results demonstrate that, under identical I_{DS} stress, the negative V_{ON} shift is accelerated with the increase in T_{ITZO} .

Generally, the positive V_{ON} shift was due to electron trapping at the front-channel interface, while the V_{ON} shift to the negative V_{GS} direction was due to hole trapping at the active layer/etch-stopper interface under the I_{DS} stress. For the 45 nm T_{ITZO} device under low I_{DS} ($< 180 \mu A$) stress ($V_{DS} = V_{GS}$), electrons drifted to the gate insulator/ITZO region. Simultaneously, electron trapping occurred immediately at the gate insulator/ITZO interface, as illustrated in the corresponding schematic diagram (Figure 8a).

Figure 6. Evolution of transfer characteristics as a function of 10^4 s DCS duration with the test temperature of 50°C for the devices with a T_{ITZO} of 45 nm under I_{DS} stresses of (a) 10, (b) 60, (c) 120, and (d) 180 μA ; with a T_{ITZO} of 75 nm under I_{DS} stresses of (e) 10, (f) 60, (g) 120, and (h) 180 μA ; and with a T_{ITZO} of 100 nm under I_{DS} stresses of (i) 10, (j) 60, (k) 120, and (l) 180 μA .

Figure 7. Variation in the ΔV_{ON} with DCS duration for the TFT devices measured at I_{DS} stresses of (a) 10, (b) 60, (c) 120, and (d) 180 μA .

Figure 8. The schematic diagram of impact ionization mechanism of DCS-originated instability in the devices with a T_{ITZO} of (a) 45 and (b) 75 and 100 nm.

As the I_{DS} stress increases, the electron trapping probability is enhanced. When the I_{DS} increases to 180 μA , electron trapping is the main origin of the positive V_{ON} shift within the stress duration of 1000 s. Consequently, a saturated trapping behavior is then observed. When the stress time exceeds 3000 s, hole trapping seems to become a major reason for the slightly negative V_{ON} shift. It can be explained by the impact ionization phenomenon [21], which induces the generation of an electron-hole pair. Consequently, the excited charges are trapped at the front- and back-channel interfaces. However, the electron trapping seems to become saturated at the gate insulator/ITZO region. Therefore, the extra electrons are drained from the drain electrode. The holes generated near the drain side migrate to the source region along the back-channel interface and accumulate near the source region. As a result, the V_{ON} shifts from a positive to negative V_{GS} direction. When the T_{ITZO} increases to 75 nm and more, a clear negative V_{ON} shift is observed under various I_{DS} stresses, demonstrating that hole trapping at the ITZO/etch-stopper interface is the main cause of the negative V_{ON} shift. With the increase in the T_{ITZO} , the negative V_{ON} shift is accelerated under the identical I_{DS} stress. The results demonstrate that, for the thicker T_{ITZO} TFTs, electrons injected from the source will experience a longer duration prior to reaching the gate insulator/ITZO interface under the vertical electric field. Simultaneously, electrons are subjected to a driving force from the lateral electric field. It is noted that the identical I_{DS} bias is controlled with different $V_{GS} = V_{DS}$ values for various T_{ITZO} TFTs. Therefore, the probability of electron-induced impact ionization is greatly increased with sufficient space and time, contributing to more excited carriers (Figure 8b). It is noted that the forward and reverse transfer curves were compared after DCS, and the similar transfer curves were obtained without SS degradation. Therefore, the results suggest that the observed phenomenon is hard to attribute to the increase in the donor-like states near the source side of the TFTs.

On the basis of the above-mentioned discussions, the obtained results suggest that, in the high- μ devices, the DCS-induced impact ionization is dependent on the generation of electron-hole pairs, which is closely proportional to the channel layer thickness, test temperature, applied electric field, and drain current density. In other words, the structural design of the devices and the control of test conditions should be well considered to promote the stability performance of the devices.

4. Conclusions

In summary, the ITZO TFTs with various T_{ITZO} were fabricated and the DCS-induced instabilities under different test temperatures and I_{DS} values were investigated. All the TFT devices possessed excellent electrical properties irrespective of the T_{ITZO} , including a high μ_{sat} of $>35 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ and steep SS. For 100 nm T_{ITZO} devices evaluated at high V_{GS} and V_{DS} values, the transfer and output characteristics exhibited an abnormal rise in current. This phenomenon can be ascribed to the floating body effect that impacts ionization occurring near the drain region. More importantly, with the variation in the T_{ITZO} , the synergistic effects of temperature and I_{DS} value on DCS-induced instability were well understood. The results further demonstrate that the abnormal negative shift behavior in TFT devices with the T_{ITZO} of greater than 75 nm is gradually enlarged with the increase in temperature and I_{DS} values. This study provides a method with which to comprehend the DCS-originating degradations for high-performance ITZO-based TFT devices.

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References

1. Nomura, K.; Ohta, H.; Takagi, A.; Kamiya, T.; Hirano, M.; Hosono, H. Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors. *Nature* **2004**, *432*, 488–492. [[CrossRef](#)] [[PubMed](#)]
2. Hirao, T.; Furuta, M.; Hiramatsu, T.; Matsuda, T.; Li, C.; Furuta, H.; Hokari, H.; Yoshida, M.; Ishii, H.; Kakegawa, M. Bottom-gate zinc oxide thin-film transistors (ZnO TFTs) for AM-LCDs. *IEEE Trans. Electron Devices* **2008**, *55*, 3136–3142. [[CrossRef](#)]
3. Shin, K.Y.; Tak, Y.J.; Kim, W.-G.; Hong, S.; Kim, H.J. Improvement of Electrical Characteristics and Stability of Amorphous Indium Gallium Zinc Oxide Thin Film Transistors Using Nitrocellulose Passivation Layer. *ACS Appl. Mater. Interfaces* **2019**, *9*, 13278–13285. [[CrossRef](#)] [[PubMed](#)]
4. Lee, Y.L.; Lee, C.H.; Nam, T.; Lee, S.; Oh, I.-K.; Yang, J.Y.; Choi, D.W.; Yoo, C.; Kim, H.-J.; Kim, W.-H.; et al. Hydrogen barrier performance of sputtered La₂O₃ films for InGaZnO thin-film transistor. *J. Mater. Sci.* **2019**, *54*, 11145–11156. [[CrossRef](#)]
5. Wang, C.-J.; You, H.-C.; Ou, J.-H.; Chu, Y.-Y.; Ko, F.-H. Ultraviolet Photodetecting and Plasmon-to-Electric Conversion of Controlled Inkjet-Printing Thin-Film Transistors. *Nanomaterials* **2020**, *10*, 458. [[CrossRef](#)]
6. Barros, R.; Saji, K.J.; Waerenborgh, J.C.; Barquinha, P.; Pereira, L.; Carlos, E.; Martins, R.; Fortunato, E. Role of Structure and Composition on the Performances of P-Type Tin Oxide Thin-Film Transistors Processed at Low-Temperatures. *Nanomaterials* **2019**, *9*, 320. [[CrossRef](#)]
7. Zan, H.-W.; Yeh, C.-C.; Meng, H.-F.; Tsai, C.-C.; Chen, L.H. Achieving High Field-Effect Mobility in Amorphous Indium-Gallium-Zinc Oxide by Capping a Strong Reduction Layer. *Adv. Mater.* **2012**, *24*, 3509–3514. [[CrossRef](#)]
8. Wang, C.-J.; You, H.-C.; Lin, K.; Ou, J.-H.; Chao, K.-H.; Ko, F.-H. Highly Transparent and Surface-Plasmon-Enhanced Visible-Photodetector Based on Zinc Oxide Thin-Film Transistors with Heterojunction Structure. *Materials* **2019**, *12*, 3639. [[CrossRef](#)]
9. Zhou, C.; Ai, Q.; Chen, X.; Gao, X.; Liu, K.; Shen, D. Ultraviolet photodetectors based on wide bandgap oxide semiconductor films. *Chin. Phys. B* **2019**, *28*, 048503. [[CrossRef](#)]
10. Zhao, W.; Li, H.; Li, D.; Liu, Z.; Wang, D.; Liu, S. Comprehensive investigation of sputtered and spin-coated zinc oxide electron transport layers for highly efficient and stable planar perovskite solar cells. *J. Power Sources* **2019**, *427*, 223–230. [[CrossRef](#)]
11. Li, H.; Li, D.; Zhao, W.; Yuan, S.; Liu, Z.; Wang, D.; Liu, S. NaCl-Assisted Defect Passivation in the Bulk and Surface of TiO₂ Enhancing Efficiency and Stability of Planar Perovskite Solar Cells. *J. Power Sources* **2020**, *448*, 227586. [[CrossRef](#)]
12. Wang, D.; Li, C.; Furuta, M. Influence of Active Layer Thickness on Performance and Reliability of InSnZnO Thin-film Transistors. In Proceedings of the 19th International Workshop on AM-FPD, Kyoto, Japan, 4–6 July 2012; pp. 159–162.
13. Nakata, M.; Zhao, C.; Kanicki, J. DC sputtered amorphous In–Sn–Zn–O thin-film transistors: Electrical properties and stability. *Solid State Electron.* **2016**, *116*, 22–29. [[CrossRef](#)]
14. Park, H.-W.; Park, K.; Kwon, J.-Y.; Choi, D.; Chung, K.-B. Effect of active layer thickness on device performance of tungsten-doped InZnO thin-film transistor. *IEEE Trans. Electron Devices* **2016**, *64*, 159–163. [[CrossRef](#)]

15. Park, J.; Kim, Y.S.; Kim, J.H.; Park, K.; Park, Y.C.; Kim, H.-S. The effects of active layer thickness and annealing conditions on the electrical performance of ZnON thin-film transistors. *J. Alloy. Compd.* **2016**, *688*, 666–671. [\[CrossRef\]](#)
16. Yang, Z.; Yang, J.; Meng, T.; Qu, M.; Zhang, Q. Influence of channel layer thickness on the stability of amorphous indium zinc oxide thin film transistors. *Mater. Lett.* **2016**, *166*, 46–50. [\[CrossRef\]](#)
17. Wang, D.; Hung, M.P.; Jiang, J.; Toda, T.; Furuta, M. Suppression of degradation induced by negative gate bias and illumination stress in amorphous InGaZnO thin-film transistors by applying negative drain bias. *ACS Appl. Mater. Interfaces* **2014**, *6*, 5713–5718. [\[CrossRef\]](#)
18. Zhang, J.; Yang, J.; Li, Y.; Wilson, J.; Ma, X.; Xin, Q.; Song, A. High performance complementary circuits based on p-SnO and n-IGZO thin-film transistors. *Materials* **2017**, *10*, 319. [\[CrossRef\]](#)
19. Lee, S.; Chen, Y.; Kim, J.; Kim, H.-M.; Jang, J. Transparent AMOLED display driven by split oxide TFT backplane. *J. Soc. Inf. Disp.* **2018**, *26*, 164–168. [\[CrossRef\]](#)
20. Chen, Y.; Geng, D.; Jang, J. Integrated Active-Matrix Capacitive Sensor Using a-IGZO TFTs for AMOLED. *IEEE J. Electron Devices Soc.* **2018**, *6*, 214–218. [\[CrossRef\]](#)
21. Wang, D.; Zhao, W.; Li, H.; Furuta, M. Drain Current Stress-Induced Instability in Amorphous InGaZnO Thin-Film Transistors with Different Active Layer Thicknesses. *Materials* **2018**, *11*, 559. [\[CrossRef\]](#)
22. Yue, L.; Pu, H.-F.; Li, H.-L.; Pang, S.-J.; Zhang, Q. Effect of active layer thickness on device performance of a-LZTO thin-film transistors. *Superlattice Microstruct.* **2013**, *57*, 123–128. [\[CrossRef\]](#)
23. Lee, S.; Jeon, S.; Nathan, A. Modeling Sub-Threshold Current–Voltage Characteristics in Thin Film Transistors. *J. Disp. Technol.* **2013**, *9*, 883–889.
24. Kamiya, T.; Hosono, H. Material characteristics and applications of transparent amorphous oxide semiconductors. *NPG Asia Mater.* **2010**, *2*, 15–22. [\[CrossRef\]](#)
25. Choi, H.-S.; Jeon, S.; Kim, H.; Shin, J.; Kim, C.; Chung, U.I. The impact of active layer thickness on low-frequency noise characteristics in InZnO thin-film transistors with high mobility. *Appl. Phys. Lett.* **2012**, *100*, 173501. [\[CrossRef\]](#)
26. Valdinoci, M.; Colalongo, L.; Baccarani, G.; Fortunato, G.; Pecora, A.; Policicchio, I. Floating body effects in polysilicon thin-film transistors. *IEEE Trans. Electron Devices* **1997**, *44*, 2234–2241. [\[CrossRef\]](#)
27. Jiang, J.; Wang, D.; Matsuda, T.; Kimura, M.; Liu, S.; Furuta, M. Influence of Interface Traps on the Electrical Properties of Oxide Thin-Film Transistors with Different Channel Thicknesses. *J. Nano Res.* **2017**, *46*, 93–99. [\[CrossRef\]](#)
28. Li, Y.; Pei, Y.L.; Hu, R.Q.; Chen, Z.M.; Zhao, Y.; Shen, Z.; Fan, B.F.; Liang, J.; Wang, G. Effect of channel thickness on electrical performance of amorphous IGZO thin-film transistor with atomic layer deposited alumina oxide dielectric. *Curr. Appl. Phys.* **2014**, *14*, 941–945. [\[CrossRef\]](#)
29. Lee, H.; Lin, Y.-C.; Shieh, H.P.D.; Kanicki, J. Current-scaling a-Si:H TFT pixel-electrode circuit for AM-OLEDs: Electrical properties and stability. *IEEE Trans. Electron Devices* **2007**, *54*, 2403–2410.