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Citation: [Applied Physics Letters](#) **96**, 262104 (2010); doi: 10.1063/1.3457996

View online: <http://dx.doi.org/10.1063/1.3457996>

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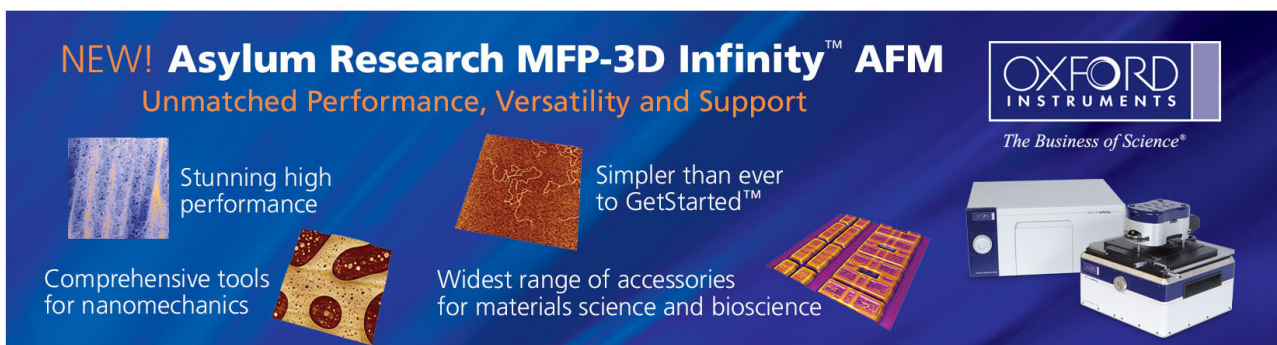
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Bias-induced oxygen adsorption in zinc tin oxide thin film transistors under dynamic stress

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(Received 4 May 2010; accepted 3 June 2010; published online 28 June 2010)

This study investigates the effects of bias-induced oxygen adsorption on the electrical characteristic instability of zinc tin oxide thin film transistors in different ambient oxygen partial pressures. When oxygen pressure is largest, the threshold voltages showed the quickest increase but the slowest recovery during the stress phase and recovery phase, respectively. This finding corresponds to the charge trapping time constant and recovery time constant, which are extracted by fitting the stretched-exponential equation and which exhibit a relationship with oxygen pressure. We suggest that the gate bias reduces the activation energy of oxygen adsorption during gate bias stress. © 2010 American Institute of Physics. [doi:10.1063/1.3457996]

A number of studies have demonstrated the benefits of amorphous oxide semiconductors (AOSs) in their visible light transparency, controllable carrier concentrations, and the prominence of quality film that can be deposited in a low temperature process.¹⁻⁴ Using ZnO-based AOSs as the active layer of thin film transistors (TFTs) shows a great capability for application on plastic substrates and for uniformity in large area deposition.⁵ ZnO-based AOS TFTs also show a great potential to replace conventional materials such as amorphous hydrogenated silicon and polycrystalline silicon. Several studies in the literature indicate that the instability of ZnO-based TFTs is different from amorphous hydrogenated silicon TFTs or polycrystalline silicon TFTs.^{6,7} The electrical characteristic stability of devices under gate bias stress is considered to be the most important issue for the development of amorphous oxide TFTs.⁸ Several studies have demonstrated that the electrical characteristics of ZnO-based transistors are very sensitive to oxygen and water.⁹⁻¹¹ Although the degradation of electrical characteristics under gate bias stress has been explained by the charge trapping model or by the influence of the ambient atmosphere,⁶ it is necessary to obtain stable electrical characteristics and research the principal mechanism which leads to threshold voltage instability under gate bias operations in different environments before applying ZnO-based TFTs to real circuit applications. However, currently there are very few studies about the environmental effect on recovery behavior after gate bias stress.

This paper examines the instability of zinc tin oxide (ZTO) TFTs originating from bias-induced oxygen adsorption. All of the dynamic stress operations under different oxygen partial pressures were performed at room temperature. The delta threshold voltage was fitted by the stretched

exponential equation to verify the mechanism producing the instability of ZTO TFTs.

Bottom-gate type ZTO TFTs were fabricated in this work. First, a 300-nm-thick molybdenum tungsten layer was deposited on the glass substrate and patterned as a bottom gate electrode, and then a 300-nm-thick silicon nitride layer was deposited as gate insulator. Next, the source and drain electrodes were formed by sputtered indium tin oxide. For the active channel layer, an 80-nm-thick ZTO film was deposited by spin-coating at room temperature and atmospheric pressure, and then baked in a furnace at 350 °C for 1 h to improve the film quality. The active channel was patterned by standard photolithography and wet etching. Finally, the TFTs were annealed at 350 °C for 1 h under ambient oxygen in the furnace.¹² Channel width and length of the ZTO TFTs were 50 μm and 5 μm, respectively. In order to study the gas ambient effect on the instability of the devices, the devices were not passivated. The current-voltage (I-V) characteristics were measured in a vacuum chamber with gas flow control and probe station by an Agilent HP4156C semiconductor parameter analyzer.

Figure 1(a) shows the I_D - V_G transfer characteristics of ZTO TFT after the gate bias stress for 1000 s in vacuum ambient (1×10^{-4} torr). The stress condition is that the gate bias was kept at $V_T + 10$ V while source and drain were grounded. The threshold voltages (V_T) of the ZTO TFTs were defined as the gate voltage where the drain current reaches 10 pA. Clearly, the I_D - V_G curve only shifts in the positive direction with tiny variations in subthreshold slope and turn-on current. In general, this result has been suggested to be due to electrons trapping in the pre-existing traps located at the interface or in the gate dielectric.^{6,7,11} After the stress, the gate bias was sequentially switched to ground to observe the recovery behavior, as shown in the inset. During the 1000 s recovery process, the I_D - V_G curves shifted back to the reverse direction. The recovery behavior is associated with detrapping of the previously trapped charges, which is

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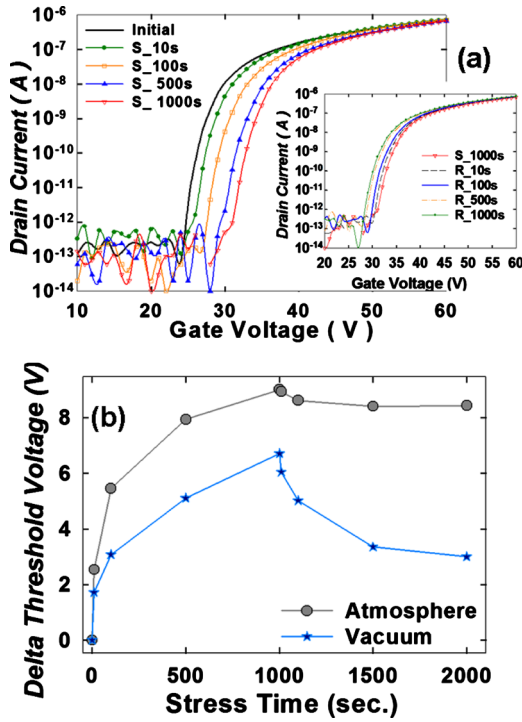


FIG. 1. (Color online) (a) Transfer I_D - V_G characteristics of ZTO TFTs under gate bias stress for 1000 s in vacuum. The inset shows I_D - V_G transfer characteristics of ZTO TFTs after removal of gate bias in vacuum. (b) Threshold voltage shift with time under dynamic stress for ZTO TFTs in different 'gas ambience (atmosphere and vacuum).

similar to findings of a previous report.¹³ Figure 1(b) shows the threshold voltage shifts during the gate bias stress and recovery phases (dynamic stress) under atmospheric and vacuum environments. Apparently, the shift in threshold voltage during the stress phase in atmospheric ambient was more serious than that in the vacuum but the recovery phenomenon in atmospheric ambient was slighter. The different threshold shifts in different stress environments has been reported to be due to the oxygen effect.¹¹ Although the recovery behavior has been observed after removing gate bias stress, the difference of recovery behaviors under different environments has yet to be discussed.¹⁴

In order to further understand the influence of oxygen on electrical characteristics of ZTO TFTs, the stresses were performed under different oxygen partial pressures. Figure 2 shows the progressive shift in threshold voltage under dy-

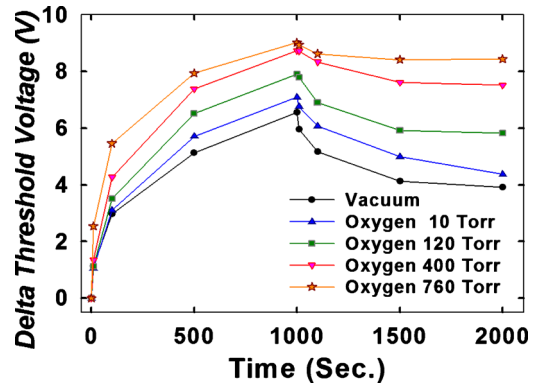


FIG. 2. (Color online) Time evolution of the delta threshold voltage after dynamic stress in different oxygen partial pressures (vacuum, 10, 120, 400, and 760 torr).

amic stress in oxygen ambient pressures of 10, 120, 400, and 760 torr. The threshold voltage shift seems to be closely connected to the amount of surrounding oxygen molecules. As the environmental oxygen increases, it exhibits the largest threshold voltage shift during the stress phase but the smallest recovery threshold voltage shift during the recovery phase. This result indicates that the charge trapping model cannot entirely account for the recovery behavior.

To address this issue, the dependence between the amount of oxygen and ΔV_T in the stress and recovery phases was examined by fitting the stretched-exponential equation from the charge trapping mechanism in a-Si TFTs.¹⁵ The stretched-exponential equation is defined as $\Delta V_T = \Delta V_{T0} \{1 - \exp[-(t/\tau)^\beta]\}$ where ΔV_{T0} is the ΔV_T at infinite time, β is the stretched-exponential exponent, and τ is the constant characteristic trapping time for stress phase or detrapping time for recovery phase. Figures 3(a) and 3(b) show the experimental data and fitting curves for the stress and recovery phases. Clearly, the experimental results were in good agreement with the stretched-exponential equation regardless of environment.

Figure 4(a) shows the decreased trapping time and increased detrapping time as the oxygen increased, which are derived by fitting the stretched-exponential equation. The trapping time and detrapping time can be regarded as the average time when oxygen adsorption and desorption occur, respectively. Several studies have suggested that the surrounding oxygen molecules can capture electrons from the

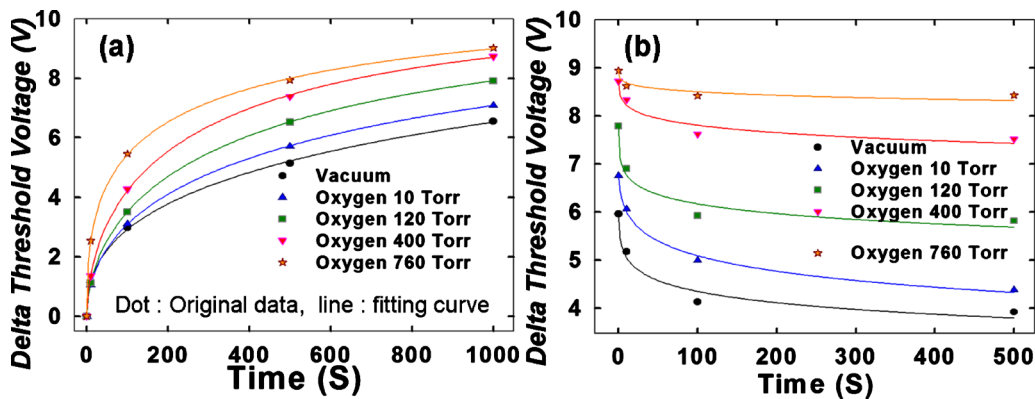


FIG. 3. (Color online) Time dependence of ΔV_T during (a) stress phase and (b) recovery phase in different oxygen partial pressures. The measured data are well fit to the stretched-exponential equation.

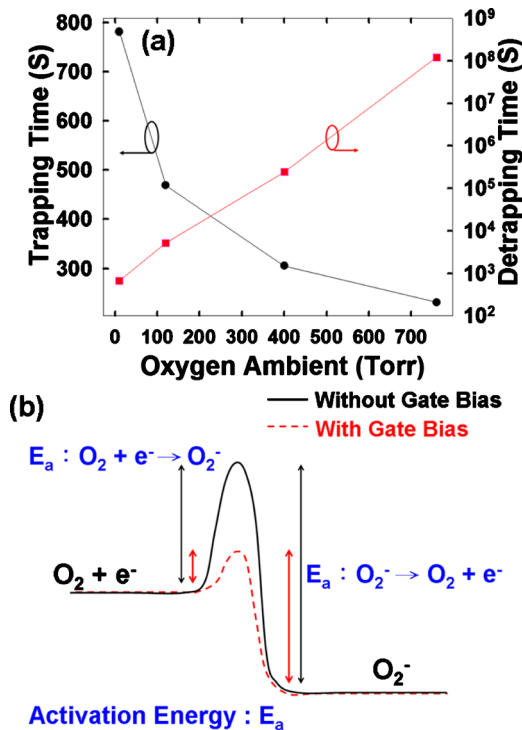


FIG. 4. (Color online) (a) Characteristic time constant (τ) for oxygen adsorption and desorption (derived by fitting stretched-exponential equation) under different ambient oxygen pressure. (b) Schematic chemical reaction model for oxygen adsorption and desorption with and without gate electrical bias.

conduction band and then adsorb on the device as a form of $O_2 + e^- \rightarrow O_{2(ads)}^-$, resulting in a depletion layer in the active backchannel and an increase in the ΔV_T of ZTO TFTs.^{9,16} This would indicate that electrical field-induced chemisorption of oxygen on the active backchannel and trapping of electrons in the interface or bulk dielectric both happen during the stress phase. The effects of the electrical field which can induce chemisorption of oxygen on zinc oxide thin film has been described in a previous study.¹⁷ One possible explanation in findings for the dynamic stress is that the electrical bias plays a role as a catalyst for the chemisorption of oxygen. The schematic activation energy with bias is shown in Fig. 4(b). With gate bias, the reduced activation energy increases the oxygen adsorption rate. Nevertheless, as shown in Fig. 4(a), the more ambient oxygen during the stress phase, the more detrapping time is needed, increasing exponentially with the oxygen pressure. During the recovery phase, it is difficult for oxygen desorption to occur without a catalyst because it requires additional energy to overcome the activation energy. Although the oxygen effect on the ZnO-based TFTs has previously been observed, the further

research on the relationship between trapping time/detrapping time and oxygen partial pressure is investigated in this work.

In summary, the electrical characteristics of ZTO TFTs under dynamic stress in a vacuum and in different ambient oxygen pressures were discussed. The threshold voltage shifts in ZTO TFTs under dynamic stress were strongly affected by the bias-induced oxygen absorption on the back-channel during the stress phase and by the amount of surrounding oxygen molecules during the recovery phase. By fitting the stretched-exponential equation, the relationship between the average time for oxygen adsorption/desorption and oxygen partial pressure can be easily extracted. This result indicates the principal mechanism which leads to the threshold voltage instability of ZTO TFTs is bias-induced oxygen adsorption occurring in the surrounding environment.

This work was performed at National Science Council Core Facilities Laboratory for Nanoscience and Nanotechnology in Kaohsiung-Pingtung area and was supported by the National Science Council of the Republic of China under Contract Nos. NSC-98-3114-M-110-001 and NSC 97-2112-M-110-009-MY3.

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