International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:5, No:4, 2011

The Light Response Characteristics of Oxide-Based Thin Film Transistors

Soo-Yeon Lee, Seung-Min Song, Moon-Kyu Song, Woo-Geun Lee, Kap-Soo Yoon, Jang-Yeon Kwon and Min-Koo Han

***Abstract*—**We fabricated the inverted-staggered etch stopper structure oxide-based TFT and investigated the characteristics of oxide TFT under the 400 nm wavelength light illumination. When 400 nm light was illuminated, the threshold voltage (V_{th}) decreased and subthreshold slope (SS) increased at forward sweep, while V_{th} and SS were not altered when larger wavelength lights, such as 650 nm, 550 nm and 450 nm, were illuminated. At reverse sweep, the transfer curve barely changed even under 400 nm light. Our experimental results support that photo-induced hole carriers are captured by donor-like interface trap and it caused the decrease of V_{th} and increase of SS. We investigated the interface trap density increases proportionally to the photo-induced hole concentration at active layer.

***Keywords*—**thin film transistor, oxide-based semiconductor, light response

I. INTRODUCTION

AMORPHOUS oxide-based thin-film transistors (TFTs) have attracted considerable attention due to the higher filed-effect mobility and good uniformity [1-2]. Oxide TFTs such as IGZO TFTs can be fabricated under low temperature(less than 350 C°) by simple process compatible to commercially available Si:H TFTs fabrication process[3-7]. Therefore, amorphous oxide-based TFTs are considered as the pixel element for active-matrix liquid crystal displays (AMLCDs) and active-matrix organic light emitting diode displays (AMOLEDs). The electrical stress issue has been improved so that the device shows good stability under negative bias stress[8]. However, threshold voltage (V_{th}) is significantly changed under the electrical and optical stress [8] and it is still not fully investigated. To understand the effect of light under electrical bias stress, the mechanism of the light at initial condition, light response characteristics, has to be investigated at the same time. In oxide TFTs, V_{th} decreases and SS increases under light illuminated condition and it is considered that it is caused by the current at the bulk region of active layer [9-10]. The purpose of our work is to investigate the light response of oxide TFTs under the 400 nm wavelength light illumination and the effect of intensity of light on the device characteristics. V_{th} decreased and SS increased under light illumination. It could be observed well only at forward sweep, while V_{th} and SS was barely changed at reverse sweep. Those phenomena couldn't be explained by increase of bulk current.

II. FABRICATION AND EXPERIMENTS

We fabricated oxide TFTs with an inverted-staggered etch stopper structure. Gate metal (Mo) was deposited by DC sputtering on a glass substrate. The gate insulator layer of SiO_2 was deposited by plasma enhanced chemical vapor deposition (PECVD) and active layer was deposited by sputtering. SiO_2 layer was formed as etch stopper. After active island was patterned, source and drain electrode (Mo) was deposited by sputtering. Fig. 1 shows the cross section of fabricated oxide TFT. The dimension of our device was 25 μm/15 μm (W/L). The channel length was defined with etch stopper layer length. We used monochromatic light with band-pass filter from Xenon lamp light source. The semiconductor analyzer was used to measure the device characteristics.

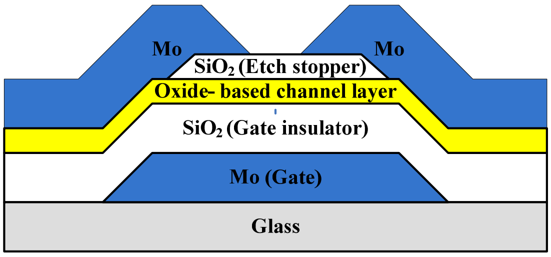


Fig. 1 Structure of fabricated oxide-based TFT

III. RESULT

When we measured the device under the various wavelength light, such as 650, 550, 450, and 400 nm, V_{th} decreased and SS increased only under 400 nm wavelength light illumination as shown in Fig. 1 (a). The device started to respond to the light having larger photon energy than optical band gap (E_{opt}) of active layer (~3 eV) [11]. This phenomenon was observed when we performed forward sweep (from V_{GS} = -20 V to 20 V), while the device characteristics were almost same even under 400 nm wavelength light at reverse sweep (from V_{GS} = 20 V to

---

Soo-Yeon Lee is with the Electrical Engineering and Computer Science Department, Seoul National University, Seoul, Korea (phone: +82-880-7992; fax: +82-2-871-7992; e-mail: xcloverx@emlab.snu.ac.kr).

Seung-Min Song is with the Electrical Engineering and Computer Science Department, Seoul National University, Seoul, Korea (phone: +82-880-7992; fax: +82-2-871-7992; e-mail: ssong85@emlab.snu.ac.kr).

Moon-Kyu Song is with the Electrical Engineering and Computer Science Department, Seoul National University, Seoul, Korea (phone: +82-880-7992; fax: +82-2-871-7992; e-mail: mk86@emlab.snu.ac.kr).

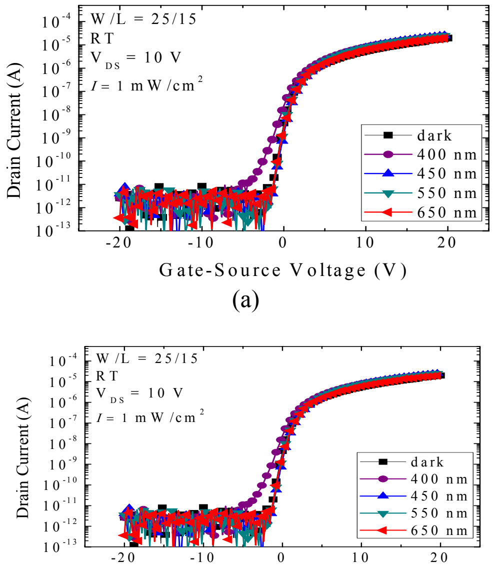
Woo-Geun Lee is with Samsung Electronics, Yongin-Si, Korea (wg2.lee@samsung.com).

Kap-Soo Yoon is with Samsung Electronics, Yongin-Si, Korea (kapsoo.yoon@samsung.com).

Jang-Yeon Kwon is with the Materials Science and Engineering Department, Seoul National University, Seoul, Korea (e-mail: jykwon@emlab.snu.ac.kr).

Min-Koo Han is with the Electrical Engineering and Computer Science Department, Seoul National University, Seoul, Korea (phone: +82-880-7992; fax: +82-2-871-7992; e-mail: mkh@snu.ac.kr).

-20 V) as shown in Fig. 1 (b). Fig. 2 shows the transfer characteristics according to the intensity of 400 nm wavelength light and each V_{th} and SS are listed in Table 1. The higher intensity of light was illuminated, the larger V_{th} shift and SS change occurred. Under any wavelength light, mobility was barely changed and it was about 8.03 cm^2/V-s.



(a)

(b)

Fig. 2 The transfer characteristics under dark, 400 nm, 450 nm, 550 nm, 650 nm at : (a) forward sweep (from V_{GS} = -20 V to 20 V) and (b) reverse sweep (from V_{GS} = 20 V to -20 V).

IV. DISCUSSION

Because the device started to respond to the light having larger photon energy than E_{opt} of active layer, it is deduced that the light response characteristics of oxide TFTs is related with the E_{opt} of active layer and the photo-induced carriers caused the V_{th} and SS change. From the result of Fig. 2, it is also found that the larger amount of carrier can cause the larger decrease of V_{th} and increase of SS because photo-induced carrier concentration is proportional to the intensity of light.Usually, the decrease of V_{th} and increase of SS under light illumination can be considered as the leakage current caused by photo-induced carriers at bulk [9-10]. In this case, however, it did not conform to the mechanism of the photo-leakage current.

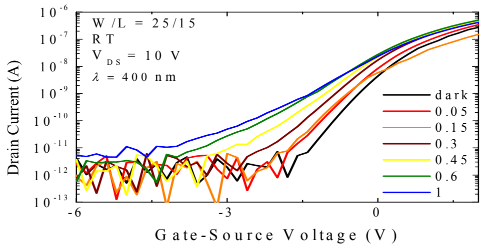
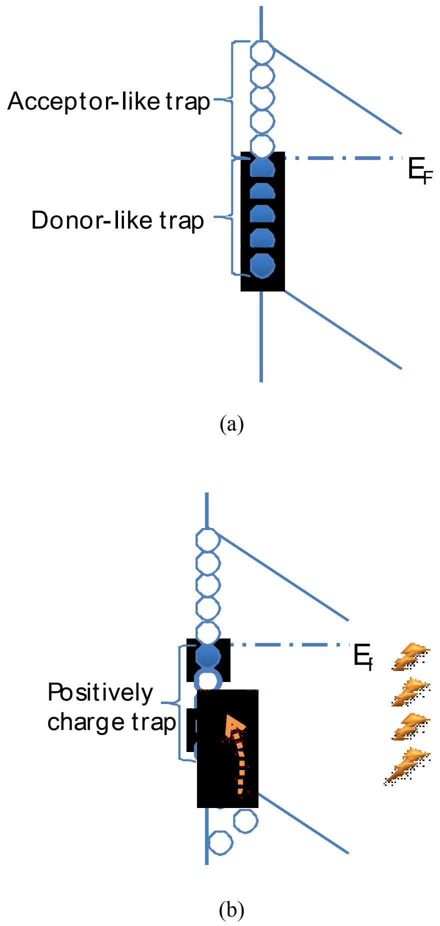


Fig. 3 Transfer characteristics under various intensity of light. Wavelength of light was 400 nm.

If the photo-induced carriers at bulk contributed to leakage current, light response would be shown not only at forward sweep, but also at reverse sweep. In terms of leakage current, even though the sweep direction is changed, the amount of leakage current will be almost same because the bias condition is same. However, in oxide TFTs, the V_{th} and SS was barely changed under light illumination compared to dark state.Because the light response of oxide TFT does not correspond to the bulk photo leakage current, we approached this phenomenon from the charge trapping at interface between active layer and gate insulator. The effect of light on device transfer characteristics is caused by photo-induced carriers and interface trap between active layer and gate insulator layer. Because the oxide TFT is more sensitive to light at forward sweep than reverse sweep, it was implied that the negative gate bias, applied at the beginning of forward sweep, influenced the device characteristics under light illumination. As for photo-induced carriers, because it reacted with the negative gate bias and the V_{th} shifted negatively, it seems that photo-induced hole carriers mainly caused the decrease of V_{th} and increase of SS. In other words, the photo-induced phenomenon of oxide TFTs is the effect of photo-induced hole carriers combined with negative bias. Figure 3 shows the energy band diagram of the interface between gate insulator and active layer when negative gate bias is applied under dark (Fig. 3 (a)) and 400 nm wavelength light illumination (Fig. 3 (b)). When negative gate bias is applied at the beginning of forward sweep, photo-induced hole carriers can drift to interface between active layer and gate insulator and form the hole channel layer. Because hole can be easily trapped by donor-like interface trap, donor-like interface trap will capture the photo-induced hole and be positively charged [10]. Then, V_{th} decreases under light illumination.

TABLE I
THRESHOLD VOLTAGE AND SUBTHRESHOLD SLOPE UNDER 400 NM WAVELENGTH LIGHT ILLUMINATION ACCORDING TO THE INTENSITY OF LIGHT

INTENSITY OF LIGHT (mW/cm^2)	THRESHOLD VOLTAGE (V)	SUBTHRESHOLD SWING (mV/dec)
Dark	0.06	470
0.05	0.05	560
0.3	-0.18	780
0.6	-0.36	1280
1	-0.21	1470



(a)

(b)

Fig. 4 Energy band diagram of the interface between gate insulator and active layer under dark and 400 nm wavelength light illumination, when negative gate bias is applied.

The increase of SS under light illumination can be also explained by interface charge trapping. As gate bias increases, Fermi level (E_F) moves toward conduction band and the electrons will fill up the energy state and trap site beneath the EF not only in the bulk of active layer but also at the interface between active layer and gate insulator. It means that the interface trap states make band bending difficult and disturb forming electron channel layer. The more energy state and trap site exist at interface, the more increase of SS occurs. As Fig. 3, at forward sweep under light illumination, donor-like state can capture the hole carriers and be empty. The total interface trap site, which electrons have to fill up, increases so that SS increases. Because positively charged interface trap increases under the light illumination, the V_{th} decreases and SS increases at forward sweep.

We quantify the interface trap density according to the intensity of light using the following equation.

$$N_t = [S\ \log(e)/((kT/q))-1]\ C_i/q \qquad (1)$$

, where S is SS and C_i is gate insulator capacitance [12]. From Figure 4, it is found that there is linear relationship between the intensity of light and N_t. Because the intensity of light is proportional to photo-induced carrier density at active layer, the increase of interface trap density is proportional to the increase of photo-induced hole concentration. This result support that the photo-induce hole carriers are trapped by donor-like state and increase interface trap density under light illumination.

V. CONCLISION

We fabricated the oxide-based TFT and investigated the characteristics under the 400 nm wavelength light illumination. When the light had larger photon energy than E_{opt} of active layer, the V_{th} decreased and SS increased under the light illumination. As the intensity of light increased, the change of transfer curve intensified. In addition, those phenomena could be observed only at forward sweep measurement and transfer curve was hardly changed at reverse sweep. Because the results did not correspond to the bulk photo leakage current, the reaction at interface between active layer and gate insulator is plausible. Therefore, it is supported that photo-induced hole carriers are captured by donor-like interface trap and it caused the decrease of V_{th} and increase of SS. We confirmed that the interface trap density increased proportionally to the photo-induced hole concentration at active layer.

REFERENCES

[1] K. Nomura, H. Ohta, K. Ueda, T. Kamiya, M. Hirano, and H. Hosono, "Thin film transistor fabricated in single-crystalline transparent oxide semiconductor", *Science*, vol. 300, no. 5623, pp. 1269–1272, May 2003.

[2] K. Nomura *et al.*,"Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors", Nature, vol. 432, no. 7016, pp. 488-492, Nov. 2004.

[3] E. Fortunato et al., "Fully transparent ZnO thin-film transistor produced at room temperature", Adv. Mater., vol. 17, no. 5, pp. 590-594, Mar. 2005.

[4] H. Yabuta, M. Sano, K. Abe, T. Aiba, T. Den, H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, "High-mobility thin-film transistor with amorphous InGaZnO4 channel fabricated by room temperature RF-magnetron sputtering", *Appl. Phys. Lett.*, vol. 89, no. 11, pp. 112 123-1–112123-3, Sep. 2006.

[5] A. Suresh et al., "Transparent, high mobility InGaZnO thin films deposited by PLD", Thin Solid Films, vol. 516, no. 7, pp. 1326-1329, 2008.

[6] P. Barquinha, L. Pereira, G. Goncalves, R. Martins, and E. Fortunato, "Toward high-performance amorphous GIZO TFTs," *J. Electrochem. Soc.*, vol. 156, no. 3, pp. H161–H168, 2009.

[7] J. Y. Kwon et al., "Bottom-Gate Gallium Indium Zinc Oxide Thin-Film Transistor Array for High-Resolution AMOLED Display", vol. 29, no. 12, pp. 1309-1311, Dec. 2008.

[8] J. S. Park et al., "Influence of Illumination on the Negative-Bias Stability of Transparent Hafnium-Indium-Zinc Oxide Thin-Film Transistors", IEEE Electron Device Letters, vol. 31, no. 5, May 2010.

[9] K. Takechi et al., "Comparison of Ultraviolet Photo-Field Effects between Hydrogenated Amorphous Silicon and Amorphous InGa ZnO_4 Thin-Film Transistors", Jpn. J. Appl. Phys., vol. 48, pp. 010203-1-010203-3, Jan. 2009.

[10] M. Kimura et al., "Mechanism analysis of photoleakage current in ZnO thin-film transistors using device simulation", Appl. Phys. Lett., vol.97, no. 16, pp. 163503-1-163503-3, Oct. 2010.

[11] T.-C. Fung et al., "Photofield-Effect in Amorphous In-Ga-Zn-O (a-IGZO) Thin-Film Transistors", Journal of Information Display, vol.9, no.4, pp. 21-29, 2008.

[12] J. K. Jeong et al., "High performance thin film transistors with cosputtered amorphous indium gallium zinc oxide channel", Appl. Phys. Lett., vol. 91, no. 91, pp. 113505-1-113505-3, Sep. 2007.