

# The Unique Phenomenon in the Amorphous $\text{In}_2\text{O}_3\text{-Ga}_2\text{O}_3\text{-ZnO}$ TFTs Degradation under the Dynamic Stress

Mami Fujii<sup>1</sup>, Ji Sim Jung<sup>2</sup>, Jang Yeon Kwon<sup>2</sup> and Yukiharu Uraoka<sup>1,3</sup>

<sup>1</sup>Nara Institute of Science and Technology, 8916-5 Takayama, Ikoma, Nara 630-0192, Japan

Phone:+81-743-72-6072 Fax:+81-743-72-6079 E-mail:f-mami@ms.naist.jp

<sup>2</sup>Samsung Advanced Institute of Technology, Nongseo-Dong, Giheung-Gu, Yongin-Si, Gyeonggi-Do, 446-712, Korea

<sup>3</sup>CREST, Japan Science and Technology Agency, Honcho, Kawaguchi, Saitama 332-0012, Japan

## 1. Introduction

Oxide semiconductors have attracted considerable attention as promising materials for driving thin-film transistors (TFTs) of new displays and transparent electronics. To achieve the practical use of the amorphous  $\text{In}_2\text{O}_3\text{-Ga}_2\text{O}_3\text{-ZnO}$  (a-IGZO) TFTs, we fabricated the TFTs using the conventional process compatible with the a-Si TFTs mass production line. We obtained the good initial properties of a-IGZO TFTs. However, these TFTs do not have enough reliability. We have reported the reliability under the constant voltage stress and the joule-heating from the channel caused by the drain current. When the a-IGZO TFTs are used in the real circuit, not only DC stress, but dynamic (AC) stress is imposed. Therefore previous studies were not enough for considering the actual TFTs performance under the circuit.

In this study, we evaluated the reliability of a-IGZO TFTs by applying AC stress. And then we calculated the TFTs characteristics to reproduce the experimental results. This will enable us to identify the type of trap density that influences electrical properties. It is absolutely essential to study the reliability under the AC stress.<sup>1</sup> And we aim fabricating highly reliable a-IGZO TFTs for next generation displays.

## 2. Experimental

The a-IGZO TFTs used in this study is bottom gate structure as shown in Fig.1. The fabricated TFTs were annealed for 1 hour at 350°C in the nitrogen ambient. For the TFTs, various gate voltages were applied as electric stress and changes in electrical properties were examined to evaluate reliability at room temperature in the atmosphere.

The AC stress with minimum -20 V and maximum 20V is imposed on the gate electrode for 10000 seconds. TFTs characteristics under the constant voltage stresses were measured to examine the effects of plus-minus transition of AC stress voltage. And the TFTs characteristics were measured after 1, 10, 100, 1000, 10000 second(s). In order to remove the DC effect, source and drain electrodes were grounded. In this measurement, frequency was varied from 1 kHz to 500 kHz. To clarify the ON/OFF switching effect, frequency dependence was investigated. Next, we assumed the density of state distribution model reported in our previous work and the other report.<sup>2,3</sup> And then we calculated the TFTs characteristics to reproduce the experimental results using ATLAS device simulation software. From these simulation results, we found that the densities type for the degradation due to temporal change of electrical stress.

## 3. Results and Discussion

### *V<sub>th</sub> change by the dynamic V<sub>g</sub> stress*

Figure 2 shows the change of TFTs characteristics under the AC stress. And the changes of curves under the various stresses are shown in Fig. 3. In the Fig.3 (a), (c), stress V<sub>g</sub> are DC 20V, DC -20V, and AC ±20V with 500 kHz pulse frequency. By applying AC stress of these conditions, the transfer curves shifted toward negative voltage as shown in the Fig.2 (a). Only in the case of applied AC stress, obviously subthreshold-swing (S value) increased. From Fig.2 (b), the transfer curve recovered after stopping bias stress imposition. The threshold voltage (V<sub>th</sub>) recovered during 10000-second relaxation but the S value was not decreased to initial property. This phenomenon of S value change was different from the degradation under the constant voltage stress.

We also measured the frequency dependence of AC stress by changing gate bias frequency. We found that the acceleration of degradation in V<sub>th</sub> shift and S value increased by increasing frequency by comparing to the results as shown in Fig 3 (b), (d). Higher frequency enhanced the degradation of transfer curve shift and S value increase. These results suggest that the ON/OFF transition region in the pulse, namely ON to OFF and OFF to ON, is the key of degradation in the case of AC stress. This degradation in S value increase is the unique phenomenon in the AC stress under the plus-minus transition pulse.

### *Device simulation*

We assumed the Density of State distributions model of the IGZO and simulated the TFTs characteristics during the AC stress. This model includes the positively charged donor type trap (NGD) at the 2.85 eV as shown in Fig.4, and the fixed charge in the gate insulator (DOP).<sup>2,3</sup> Figure 5 shows the parameter change of the simulated results. NGD increase accelerated with the stress frequency. After stress imposition, there is nothing marked change in the recovery properties, and recovery properties were not dependent on the stress frequencies. And the TFTs characteristics were not recovered completely during the 10000 sec relaxation. Compared with NGD, the amount of the DOP increase did not depend on the frequencies, but the amount of recovery depended on the frequencies. The TFTs characteristics recovered easily in the low stress frequency. Here, NGD have a serious impact on the S value change because it is assumed in the vicinity of fermi level. Fixed charges affect the V<sub>th</sub> parallel shift. S value increased as NGD increase, and TFTs characteristics shifted toward negative voltage

with fixed charge increase. Therefore parallel shift recovers easily, but S value recovers hardly.

**Degradation mechanism**

From these measurements, we proposed the model of degradation under the AC stress applied to the gate electrode as shown in Fig. 6. The degradation under the AC stress, ON/OFF transition region is the key as mentioned above. In this case, electrons in the source and drain electrodes can drift into the channel region. The CBM of channel region is lifted up with applying positive gate voltage. Here, electrons in the channel region sweep out to the source and drain electrodes. When the gate voltage switching occurs, high electric fields are applied in the interfaces between electrodes and channel for electrons to obtain high energy at source and drain region. These high energy electrons cut some weak bonds in the oxide semiconductor and generate defect states. In particular, these states are generated by impact ionization when these electrons attack the interface due to higher potential barrier caused by negative switching. Therefore, the interfaces between source, drain electrodes and channel are electrically damaged by high energy electrons. There is a possibility that new type states are generated by impact ionization of these electrons with high energy.

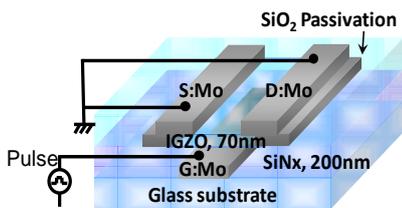


Fig.1 Schematic image of IGZO TFT used in this study

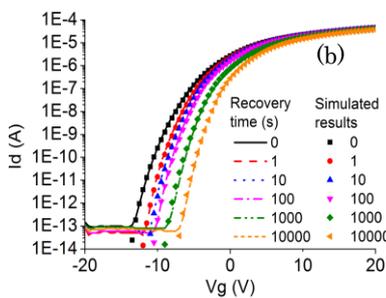
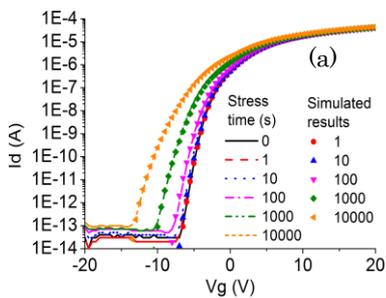


Fig.2 TFTs characteristics under the AC stress of  $\pm 20V$ , 500kHz (a) and recovery properties (b) with in each simulated results

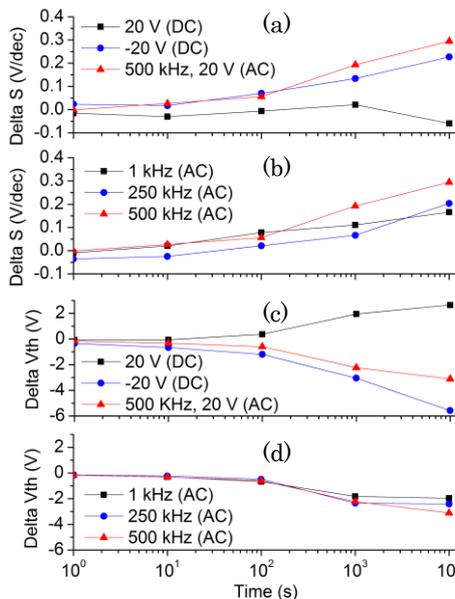


Fig.3 TFTs characteristics change under the various stress voltages

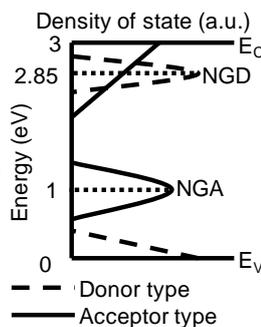


Fig.4 DOS model used in simulation

**4. Summary**

We investigated the degradation of a-IGZO thin film transistors caused by the AC stress. When the AC stresses are applied to the gate electrode of the a-IGZO TFTs, the transfer curves show the S value increase and Vth change. The TFTs characteristics did not show the S value increase under the constant gate voltage stresses, hence the degradation on the S value is a unique phenomenon by the AC stress. This degradation is accelerated by the frequency of AC stress. We found that the S value change caused by the Negatively-charged Donor like traps using device simulation. Results obtained in this study are very important in fabrication of highly reliable TFT for next generation displays.

**References**

[1] Y. Uraoka, T. Hatayama, T. Fuyuki, T. Kawamura and Y. Tsuchihashi, IEEE/Trans. Electron Device Vol.48, No.10, pp.2370-2374, 2001  
 [2] Mami Fujii, Yukiharu Uraoka, Takashi Fuyuki, Ji Sim Jung, and Jang Yeon Kwon, Jpn. J. Appl. Phys, 48 (2009) 04C091.  
 [3] Toshio Kamiya and Hideo Hosono: NPG Asia Mater. 2(1) (2010) 15-2

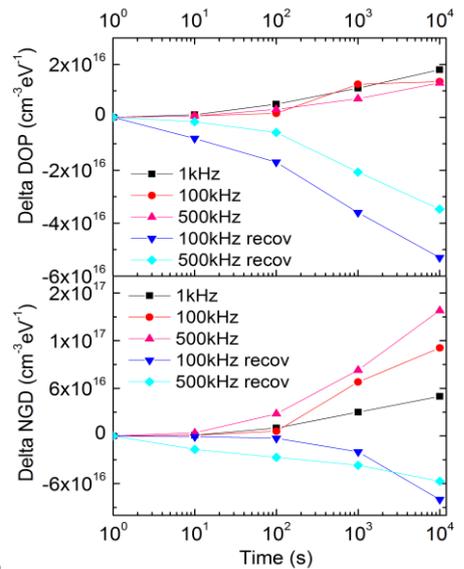


Fig.5 Simulated parameter change under the various AC stress frequencies with stress time.

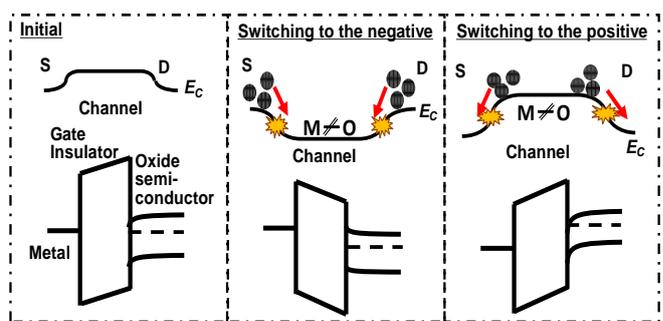


Fig.6 Degradation model under the dynamic Vg stress