Effect of Fluorine Doping on Illumination Stability of Solution-Processed IGZO TFTs

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Keywords: oxide semiconductor, thin-film transistors, a-IGZO, fluorine, passivation.

ABSTRACT

This study investigated the effect of F doping though NBIS comparison between F-doped and conventional IGZO TFTs. The oxygen vacancies in the IGZO layer were reduced and the bandgap of the IGZO was widened by F doping. As a result of this, the illumination stability of F doped-TFTs was improved.

1 INTRODUCTION

Amorphous oxide semiconductor thin-film transistors (AOS-TFTs) have attracted considerable attention for use in next generation flat panel. In particular, IGZO thin film transistors using an In-Ga-Zn-O mixture have attracted due to their excellent electrical characteristics such as high on/off ratio, good uniformity, low processing temperature, and high adaptability to various fabrication processes [1].

Various vacuum processes such as sputtering, pulsed laser deposition (PLD) and atomic layer deposition (ALD) have been used to deposit IGZO thin films. However, these methods are not suitable for large area applications and low-cost production. To overcome these disadvantages, solution-processed IGZO has been widely studied.

However, degradation of solution-processed IGZO TFT under illumination stress is an important issue in display industrial. Illumination stress instability of IGZO TFTs has been widely investigated. Many groups reported the mechanism of illumination stress instability as the excitation of electrons from the sub-gap state (such as, oxygen vacancy, weakly bonded oxygen) to the conduction band minimum. Especially, under negative bias stress, generated free holes are likely to immigrate toward the gate insulator interface and then trapped by defects or further injected into the gate insulator. There are two possible solution to improve the NBIS. (i)reduction of the oxygen vacancy (sub-gap state) or (ii) widening the band gap of active layer to hinder the photoexcitation. Ji et al. investigated the Improved NBIS stability IGZO through the high-pressure annealing under 10atm O_2 ambient.[1] This improvement occurred through a reduction in oxygen vacancy defects in the IGZO film, indicating that a photoinduced transition from V_O to V_O^{2+} was responsible for the NBIS-induced instability. In this study investigated the effect of F doping though NBIS comparison between F-doped TFTs and

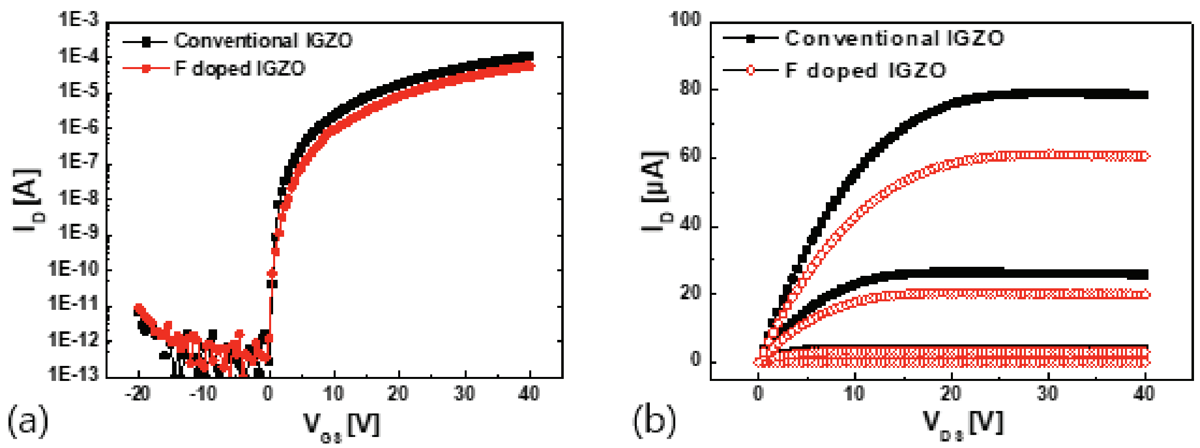

Fig. 1 (a) I-V transfer curves, (b) output characteristics of conventional and F doped IGZO TFT

Table 1 Comparison of the electrical characteristics of conventional and F doped IGZO TFTs

	μ_{sat} [$cm^2/V\cdot s$]	V_{th}[V]	I_{on}/I_{off}
Conventional IGZO	**1.54**	**4.6**	**~5×10^7**
F doped IGZO	**1.17**	**4.7**	**~3×10^7**

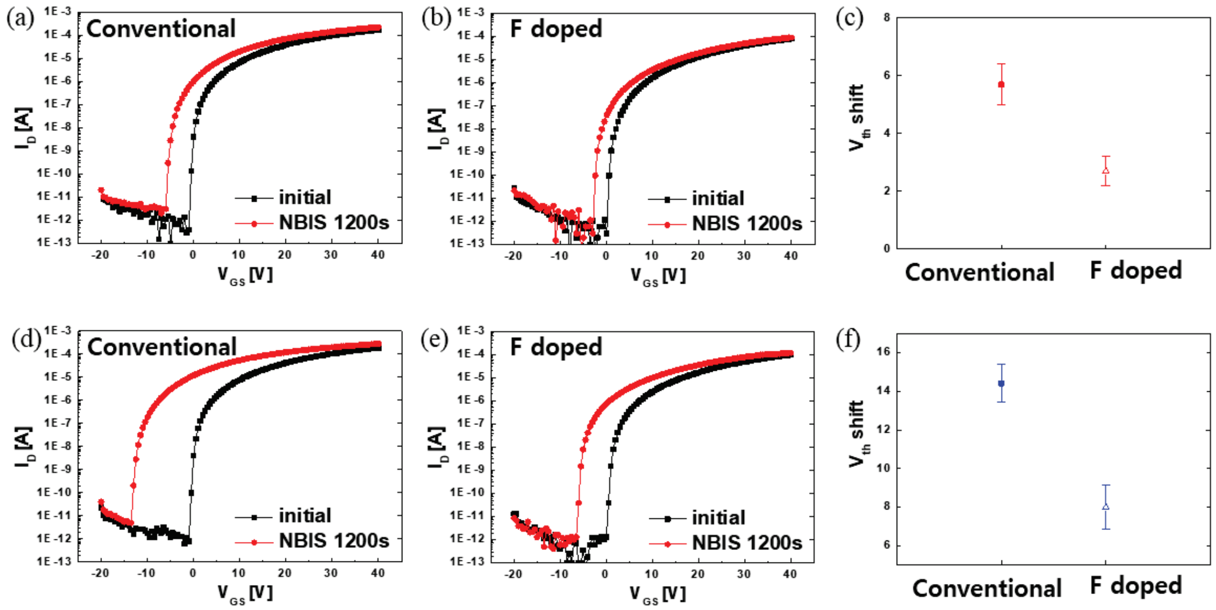

Fig. 2 Variability of Vth after NBIS 1200s with different wavelength illumination; (a), (b), (c) 660 nm (d), (e), (f) 415 nm

conventional TFTs.

2 EXPERIMENT

2.1 Precursor Solution Synthesis.

A 0.1 M IGZO precursor solution was prepared by directly dissolving Indium (III) nitrate hydrate (In (NO3)3 · xH2O)), galliumnitrate hydrate (GaN3O9 · xH2O), and zinc acetate dehydrate ((C2H3O2)2 · Zn · 2H2O) in 2-metoxyehanol. These components were mixed to achieve a 7:1:2 molar ratio of In:Ga:Zn. The solution was stirred for 12 h under ambient conditions and filtered through 0.1 μm polytetrafluoroethylene (PTFE) syringe filters, before spin-coating. All reagents were purchased from Sigma-Aldrich and were used without further purification. To prepare the 3% CYTOP precursor solution, a 9% CYTOP (AGC) was diluted in CT-SOLV180 (AGC). The solution was stirred for 12 h under ambient conditions.

2.2 Device Fabrication.

In this work, bottom-gate/top- contact IGZO TFTs were fabricated using a solution process as shown in Fig. 1(a). All the devices were made on boron-highly doped silicon substrate with thermal oxidized SiO_2. The p+-Si substrate was used as a gate electrode and the SiO_2 of 200 nm was used as a gate insulator (GI). The Si-substrates were cleaned with acetone and isopropyl alcohol (IPA) in an ultrasonic cleaner. For a smooth coating, UV/ozone treatment was performed on a SiO_2 surface for 10 min. Then, the synthesized indium-gallium-zinc-oxide (IGZO) solution was coated by spin coating at 4000 rpm for 30 seconds. After spin coating, UV/ozone treatment was performed for 2hours to improve the property of the IGZO, and then the IGZO film was annealed at 350°C for 3hours. Annealed IGZO film was patterned through photolithography. the thickness of the IGZO film was measured to be about 10 nm using Atomic Force Microscope (AFM, Park system XE-100). A source and drain with 60 nm thick Al were deposited by thermal evaporation using a shadow mask. The channel width (W) and length (L) were 1000 μm and 100 μm, respectively. Finally, CYTOP solution was coated by spin coating at 3500 rpm for 60 seconds and annealed at 350°C for 2hours.

2.3 Precursor Solution Synthesis.

The current-voltage characteristics and stability of the TFTs were measured by Agilent 4145 B electrical parameter analyzer.

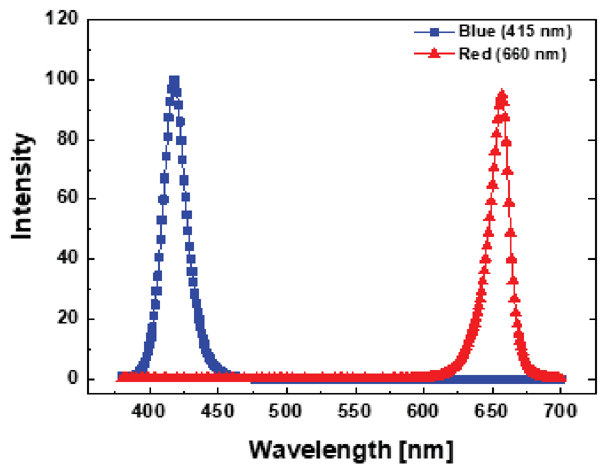

Fig. 3 Intensity of LED lamp used in NBIS measurement with different color; blue (415 nm) and red (660 nm

3 RESULTS

This study investigated the effect of F doping though NBIS comparison between F-doped TFTs and conventional TFTs. Fig 1. shows that the I-V transfer and output characteristic of conventional and F-doped IGZO TFTs, and the parameters of each TFT are summarizes in Table 1. As shown in Table 1. and Fig 1., on current of F-doped IGZO TFTs is decrease. This is due to the reduction of the oxygen vacancies (Vo) by the F doping, and also the reduction of Vo leads to increase the threshold voltage (V_{th}) [2]. Fluorine can easily substitute for V_o in the IGZO like the (1), because of the similar ionic radii of Fluorine and Oxygen.

$$V_o^{2+} + 2e^- + F^- \leftrightarrow F_o + e^- \quad (1)$$

To investigate the effect of Fluorine doping, the NBIS was measured. NBIS was measured according to the stress time under the illumination and negative bias with a gate voltage of -20V. In the case of the F doped IGZO TFTs, reliability of the electrical characteristics under the negative bias illumination stress was improved as shown in Fig 2. In the case of the conventional IGZO TFTs, Vth shift of -5.7 V was observed under 660 nm wavelength illumination and negative bias stress condition of 1200s, and -2.7 V shift was observed, in case of F-doped TFTs. d NBIS test using different wavelength (415 nm) illumination was measured. In that case -14.1 V and -8.2 V was observed, respectively. This is due to (i) defects in the active layer were reduced and (ii) optical band gap is widened through the F doping effect [3,4]. We confirmed that the V_o of F-doped IGZO were reduced through the XPS data. In addition, we measure optical band gap of F-doped IGZO and investigated the band gap of F-doped is wider than conventional IGZO. Fig 3. shows the intensity of LED lamp used in NBIS measurement with different color; blue (415 nm), and red (660 nm).

4 CONCLUSIONS

In this study, we investigated the effect of F doping though NBIS comparison between F-doped TFTs and conventional TFTs. In the case of the F doped IGZO TFTs, reliability of the electrical characteristics under the negative bias illumination stress was improved This is due to (i) defects in the active layer were reduced and (i i) optical band gap is widened through the F doping effect. We confirmed that the Vo of F-doped IGZO were reduced through the XPS data. In addition, we measure optical band gap of F-doped IGZO. we confirmed that the reduction of Vo and widened IGZO bandgap through F doping effect. As a result of this the reliability of the TFTs under illumination stress are improved.

REFERENCES

[1] K.H. Ji, J-I. Kim, H.Y. Jung, S. Y. Park, R. Choi, U. K .Kim, C. S. Hwang, D. Lee, H. Hwang, and J. K. Jeong “Effect of high-pressure oxygen annealing on negative bias illumination stress-induced instability of InGaZnO thin film transistors” Appl. Phys. Lett. 98, pp103509 ,2011

[2] J. Jiang, T. Toda, M. Phi Hung, D. Wang, M. Furuta, “Highly stable fluorine-passivated In–Ga–Zn–O thin-film transistors under positive gate bias and temperature stress” Appl. Phys. Exp. vol 7, pp 114103, 2014

[3] M. Furuta, J. Jiang, M. Phi Hung, T. Toda, D. Wang, G. Tatsuoka, “Suppression of Negative Gate Bias and Illumination Stress Degradation by Fluorine-Passivated In-Ga-Zn-O Thin-Film Transistors” ECS J. Solid State Sci. Technol., vol 5, pp Q88-Q91, 2016

[4] J. Kim, J. Bang, N. Nakamura, H. Hosono, “Ultra-wide bandgap amorphous oxide semiconductors for NBIS-free thin-film transistors”, Appl. Phys. Lett. Materials., vol 7, pp 022501, 2019

[5] T. Chen, Y. Kuo, T.-C. Chang, M.-C. Chen, H.-M. Chen, "Mechanism of a-IGZO TFT device deterioration—Llumination light wavelength and substrate temperature effects", J. Phys. D Appl. Phys., vol. 50, pp. 42LT02, 2017.