Fluorine-doped Indium Gallium Zinc Oxide Thin-Film Transistors Fabricated via Solution Process

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Keywords : IGZO TFTs, Fluorine, Doping effect, Solution process.

ABSTRACT

Fluorine-doped indium-gallium-zinc-oxide thin-film transistors (IGZO TFTs) were fabricated using a sol-gel process. The devices showed the enhanced electrical properties of V_{th}, saturation mobility, subthreshold swing and positive bias stress (PBS) stability with an incorporation of the fluorine into the IGZO channel layer. This may be attributed the effect of fluorine doping. It generates the free electron by replacing the oxygen atoms and decreases the total trap states (N_T) by occupying the oxygen vacancies.

1 INTRODUCTION

Amorphous oxide semiconductor thin film transistors (AOS TFTs) have been extensively studied in the field of flat panel displays because they have many advantages such as high carrier mobility, environmental stability, optical transparency and the probability of low temperature processing in comparison with amorphous silicon (a-Si). Especially, solution-processed amorphous-oxide-based thin-film-transistors (TFTs) have attracted considerable attention for their advantages of simple process, low cost and high throughput for applications to large area display devices compared to conventional vacuum techniques[1]. Moreover, It is also convenient to prepare the precursor solutions simply in the desired composition ratios by dissolving different proportions of the metal sources and bases into the appropriate solvent. However, they have faced the limits of low carrier mobility, poor electrical stability by trap sites like oxygen vacancies[1][2]. Many research groups have reported to improve the electrical characteristics of solution processed indium-gallium-zinc-oxide TFTs[3]. Especially, IGZO doped with various elements has been developed. In general, doping by introducing electronic donors or acceptors to host crystals is a successful approach in solution processed active layer of thin films. The various elements, such as Hf, Ti, Sn, Al, and Zr, as dopants of IGZO have been extensively studied[4]. Also, the effects of fluorine passivation were researched that the fluorine decrease the electron traps in the AOS active layers[5]. In this study, we propose TFTs employing fluorine incorporated indium-gallium-zinc-oxide (IGZO:F) channel layer as doping the fluorine in the precursor solution.

2 EXPERIMENT DETAILS

Figure 1 (a) shows the device structure and Figure 1 (b) appears the fabrication process of solution processed TFTs. The P^+ type Si substrates used as a gate electrode were cleaned via RCA method. A gate insulator layer of SiO2 150 nm in thickness was formed on the substrates using a thermal oxidation method. First, the 0.1 M precursor solution for the IGZO:F was prepared by dissolving indium fluoride (InF_3), indium nitrate ($In(NO_3)_3$), gallium nitrate ($Ga(NO_3)_3$) and zinc nitrate ($Zn(NO_3)_3$) in 2-methoxyethanol for channel layers. The solution was fabricated with 10% F_3 by adjusting the ratio of InF_3 and $In(NO_3)_3$ and then stirred for 18 hrs at 75 ℃. The channel layers were spin-coated on the SiO_2 gate dielectric at 3,500 rpm for 35 s. The pre-annealing and post-deposition annealing processes were performed under 200 °C for 10 min on a hot-plate and under 350 °C for 60 min at a furnace, respectively. Al source/drain electrodes (70 nm) were deposited using a E-beam evaporator. The channel width and length were 400 and 200 μm, respectively. Current-voltage characteristics were identified using an Agilent 4156C and devices were subjected to 10 V positive gate bias stress for 1000 s.

3 RESULTS AND DISCUSSIONS

Figure 2 shows the I-V transfer characteristics of IGZO TFTs as a function of fluorine incorporation. The electrical parameters of the devices extracted from the transfer curves are summarized in Table 1. We confirmed that electrical parameters were improved by fluorine doping. The ionic radius of oxygen and fluorine is similar, which can replace an oxygen atom by fluorine atom and the difference of the electronegativity of oxygen and substituted fluorine generate a free electron[6][7]. These affected the decrease of V_{th} (1.1 V to 0.2 V), the increase of $I_{on\text{-}off}$ ratio(3.97×10^7 to 6.92×10^7) and μ_{sat} (0.19 to 0.34 $cm^2/V{\cdot}S$) by enhancing of carrier concentration in the channel layers. Also, subthreshold swing (S·S) decreased from 0.821 to 0.654 and the threshold voltage shift ($\triangle V_{th}$) after positive bias stress ($V_{G,stress}$=10 V for 1000 s) reduced from 8.15 V to

6.62 V with fluorine as shown Figure 3. These are due to the decreased the electron trap site near the channel/dielectric interface as the fluorine occupied with oxygen vacancy[6][7]. Figure 4 represents the dual roles' mechanism of the fluorine doping[6]. Also, we supposed to reduce the total trap density (N_T) in the active layer which includes the trap site near the interface. It was calculated from the parameters of subthreshold swing (S·S). The N_T can be calculated by the using following equation:

$$N_T = \left(\frac{S \log(e)}{\frac{kT}{q}} - 1 \right) \frac{C_i}{q} \; [8]. \qquad (1)$$

According to the results of the equation (1), the value of N_T decreased from 1.84×10^{12} for IGZO to 1.43×10^{12} for F doped IGZO active layer. Eventually, fluorine doping led both the higher mobility and the improved positive gate bias stability in the IGZO TFTs.

4 CONCLUSIONS

In conclusion, we confirmed that the fluorine doped IGZO TFTs showed improved electrical performance. Especially, fluorine doping enhanced both carrier mobility and electrical stability, which is the trade off in AOS TFTs. Our results recommend fluorine as a dopant material for improving the electrical performance of IGZO TFTs.

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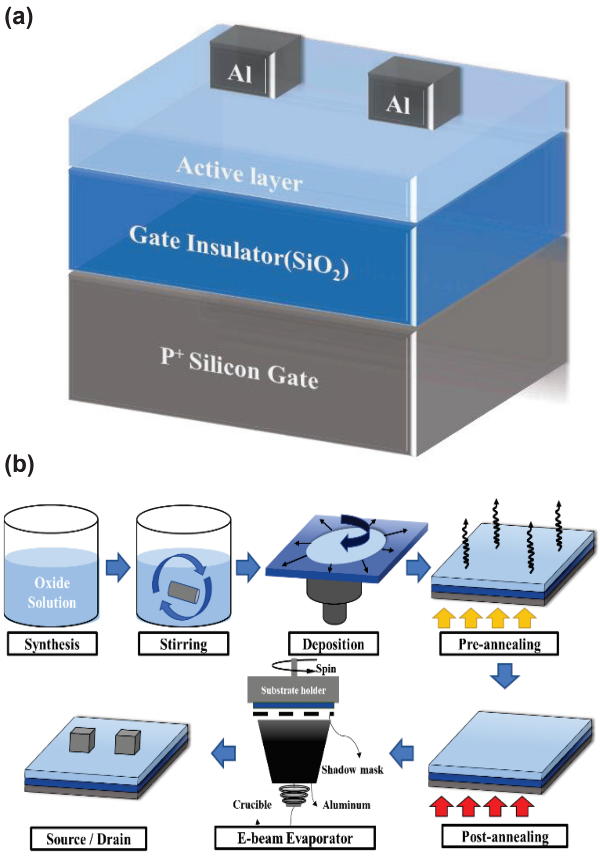


Fig.1 (a) The structure and (b) the fabrication process of solution processed thin film transistors

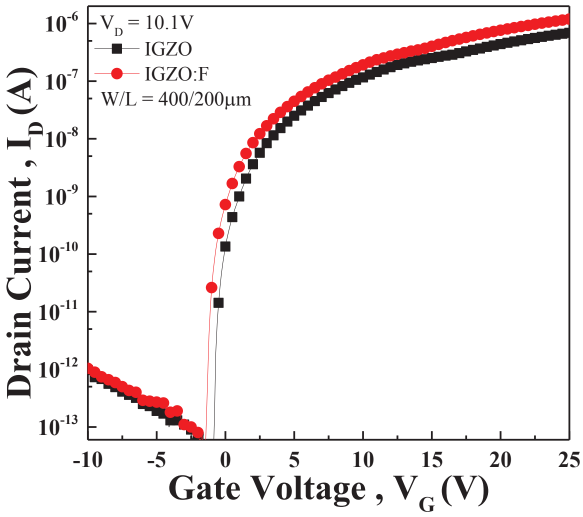
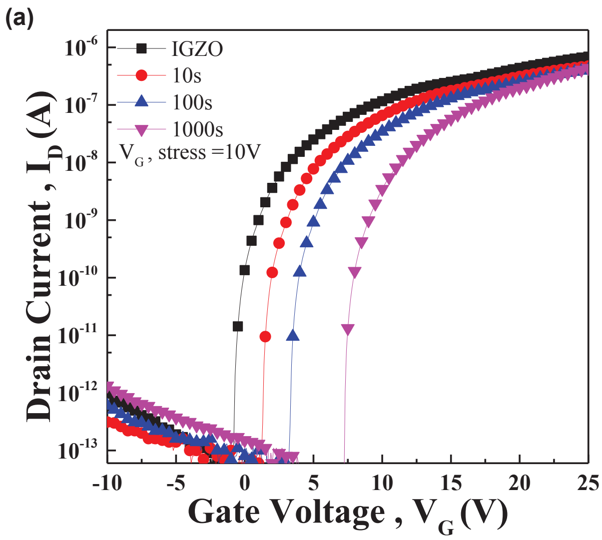
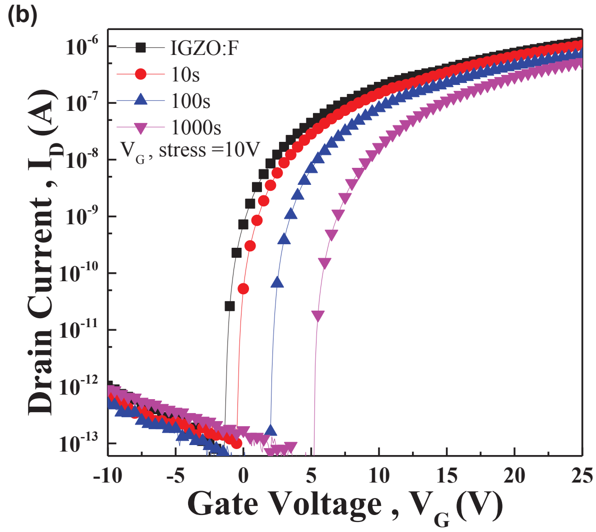


Fig.2 Transfer characteristics of virgin and fluorine doped IGZO TFTs

Table 1 Extracted electrical parameters of IGZO TFTs with and without fluorine incorporation

Parameters \ Channel layers	IGZO	IGZO:F
V_{th}(V)	1.1	0.2
μ_{sat} (cm^2/V·S)	0.19	0.34
S·S (V/decade)	0.821	0.654
$I_{on\text{-}off}$ ratio	3.97×10^7	6.92×10^7
N_T (/cm^2)	1.84×10^{12}	1.43×10^{12}
V_{th} shift (1000s)	8.15V	6.62V





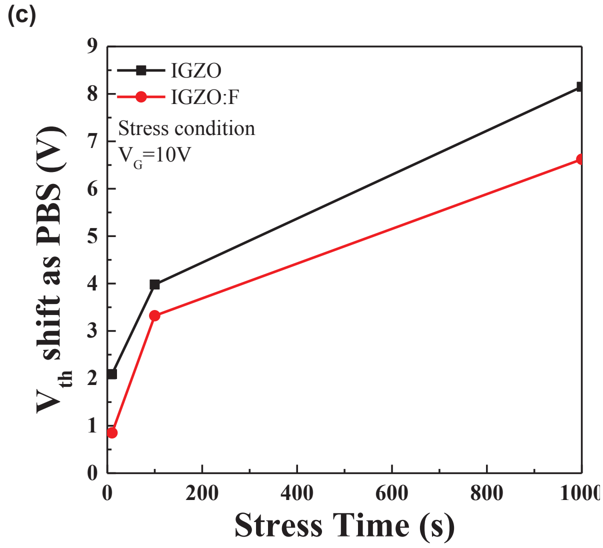


Fig.3 Transfer curves of (a) IGZO TFTs and (b) IGZO:F TFTs after positive bias stress and (c) the value of $\triangle V_{th}$ after PBS

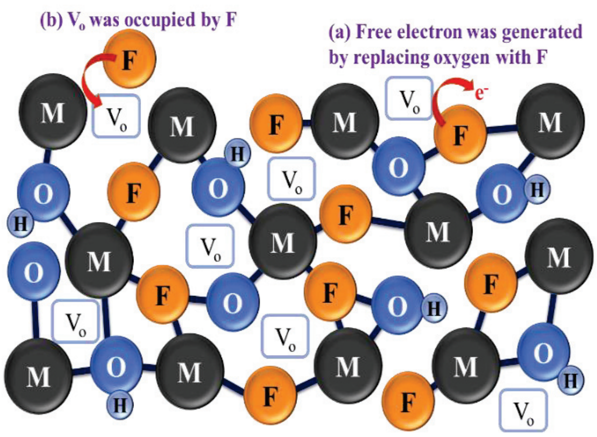


Fig.4 The mechanism of fluorine doping effect in IGZO active layers