Transfer Characteristics of H_2O_2-Doped ZrInZnO Thin Film Transistors

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ABSTRACT

Solution-processed zirconium-indium-zinc-oxide thin-film transistors (ZIZO TFTs) were fabricated with and without hydrogen peroxide (H_2O_2). With an incorporation of H_2O_2 into the channel layer, threshold voltage shift under positive bias stress were improved. We realized the reduced trap density of ZIZO TFTs with 2 M H_2O_2 incorporation.

1 INTRODUCTION

Recently, amorphous-oxide-semiconductor (AOS) thin-film-transistors (TFTs) have been studied because they have high mobility, transparency and environmental stability [1]. One of several process, solution process has advantages of low cost and simple process compared to vacuum process due to no require expensive and complicated deposition equipment for AOS TFTs fabrication [2]. Many elements with heavy metal cations such as Zr, Hf, Al and La were proposed to replace Ga in InZnO, a representative material of AOS. Among them, zirconium-indium-zinc-oxide (ZIZO) has been considered as one of the AOS channel material candidates for TFTs [3]. However, ZIZO also has reliability issues such as threshold voltage (V_{th}) shift or subthreshold swing (SS) change under gate bias stress due to originated from the nature of AOS materials [4]. Several research groups have applied hydrogen peroxide (H_2O_2) doping with AOS materials to improve the devices' reliability under gate bias stress [5]. They insist on H_2O_2 treatment effectively reduces oxygen vacancies and organic related defects associated with bias stability. In this study, we discuss the positive bias stress stability of ZIZO TFTs as a function of H_2O_2 incorporation into the channel layer.

2 EXPERIMENT

Figure 1 shows the structure of the fabricated solution process AOS TFT. First, heavily doped p-type silicon wafers used as gate electrode were cleaned by RCA method. 150 nm thickness of SiO_2 gate insulator was grown on silicon substrate by thermal oxidation. A 0.2 M ZIZO solution was added Zr, In, Zn precursors in 2-methoxyethanol. Used precursors are zirconium oxychloride octahydrate ($ZrOCl{\cdot}8H_2O$), indium nitrate hydrate ($In(NO_3)3{\cdot}xH_2O$) and zinc acetate dihydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$). H_2O_2 incorporated 1 M and 2 M in a solution, respectively. A prepared solution was stirred on a hot plate at 75 ° C for 12 hours. And, it was spin-coated on the cleaned substrate at 3,500 rpm for 35 sec. Then, the as-deposited films were annealed on a hot-plate at 200 ºC for 10 min, followed by the post-deposition annealing process at 350 ºC for 1 hour in furnace. Source/drain electrodes were deposited by an e-beam evaporator with a thickness of 70 nm. Width and length of channel layer were defined as 400 and 200 μm, respectively. Electrical properties were evaluated by Agilent 4156C parameter analyzer and 10 V bias stress was applied to gate electrode for 1 to 1000 sec.

3 RESULTS AND DISCUSSION

Figure 2 shows the transfer characteristics of the ZIZO TFTs with varying H_2O_2 mole concentration. The electrical parameters of the devices were extracted by the transfer curves of Figure 1 and summarized in Table 1. As shown in Figure 1 and Table 1, the saturation mobility (μ_{sat}) decreased from 1.61 $cm^2/V{\cdot}s$ to 0.18 $cm^2/V{\cdot}s$ and V_{th} was shifted from 0.58 V to 2.40 V as H_2O_2 concentration increased. The oxygen vacancy formation process closely relates to the generation of free electrons in the oxide semiconductor, according to equation (1).

$$O_o^x = \frac{1}{2} O_{2(g)} + V_o + 2e^- \quad (1)$$

It was thought that H_2O_2 played a role of oxygen source accompanying by reduction of oxygen vacancies in the channel. This resulted in decrease of the carrier concentration, which in turn reduced the current level overall and a larger voltage is needed for the channel to be modulated. As described in Table 1, SS decreased from 0.97 V/decade to 0.79 V/decade as H_2O_2 concentration increased. Also, total trap density (N_t) extracted from referred to the literature [6] decreased from 2.20 x 10^{12} cm^{-2} to 1.76 x 10^{12} cm^{-2}, according to equation (2).

$$N_t = \left(\frac{SS \cdot log(e)}{kT/q} - 1\right)\frac{C_i}{q} \quad (2)$$

Oxygen vacancies not only generate free electrons but also act as a positively charged trap site. These are located near the interface, electrons can be captured when the device is operating. Therefore, this implied that H_2O_2 is a strong oxidant agent [5] providing oxygen atoms into the channel layer resulting in the reduction of oxygen related trap sites at the channel/insulator interface. This resulted a difference in SS associated with N_t. Figure 3 and 4 show the transfer curves and ΔV_{th} comparison of the ZIZO TFTs prior to and after a gate bias stress as a function of H_2O_2 incorporation. As shown in Figure 4, ΔV_{th} decreased with an incorporation H_2O_2 after the gate bias stress. This is because the reduction of oxygen related trap at the interface in the oxide semiconductor due to the aforementioned H_2O_2 effect. Also, as the incorporated H_2O_2 increased, the ΔV_{th} to the positive direction decreased more than twice from 4.82 V to 1.99 V. It was believed that oxygen divided from H_2O_2 is supplies to the channel layer and improve more oxygen related trap.

4 CONCLUSIONS

In this study, we investigated the reliability of ZIZO TFTs with and without H_2O_2. We confirmed that positive bias stress induced ΔV_{th} and N_t of the devices decreased with H_2O_2 incorporation. This means that the oxygen divided from H_2O_2 effectively decreases oxygen vacancy-related trap sites at the interface of channel and insulator. And incorporated H_2O_2 increased, the stability of positive bias stress was more improved. It was believed that H_2O_2 supplies more oxygen to the channel layer. We suggest H_2O_2-doped ZIZO material as a channel layer for reliable AOS TFTs.

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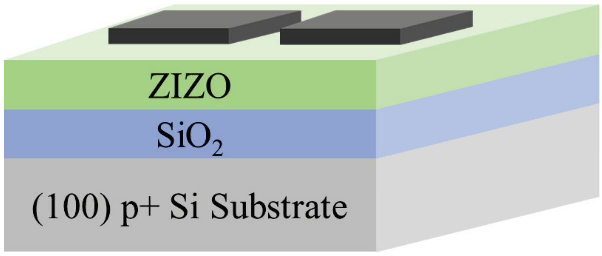

Fig. 1 Structure of solution-processed ZIZO TFTs

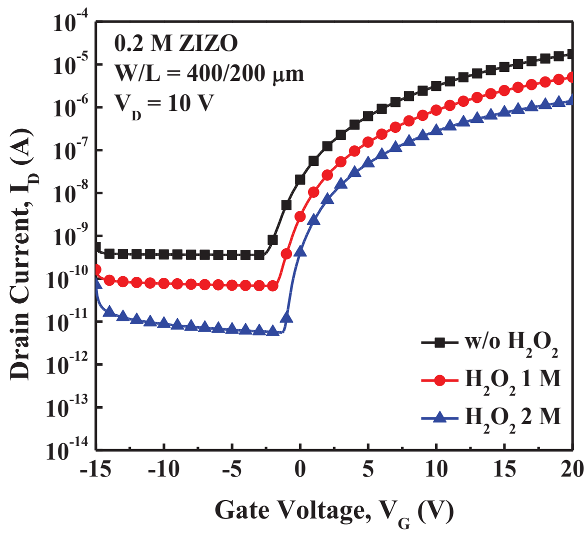

Fig. 2 Transfer curves of ZIZO TFTs with and w/o H_2O_2

Table. 1 Extracted electrical parameters of ZIZO TFTs with and w/o H_2O_2

Device	μ_{sat} ($cm^2/V{\cdot}s$)	V_{th} (V)	SS (V/decade)	N_t (cm^{-2})
w/o H_2O_2	1.61	0.58	0.97	2.20 x 10^{12}
H_2O_2 1 M	0.75	1.54	0.95	2.15 x 10^{12}
H_2O_2 2 M	0.18	2.40	0.79	1.76 x 10^{12}

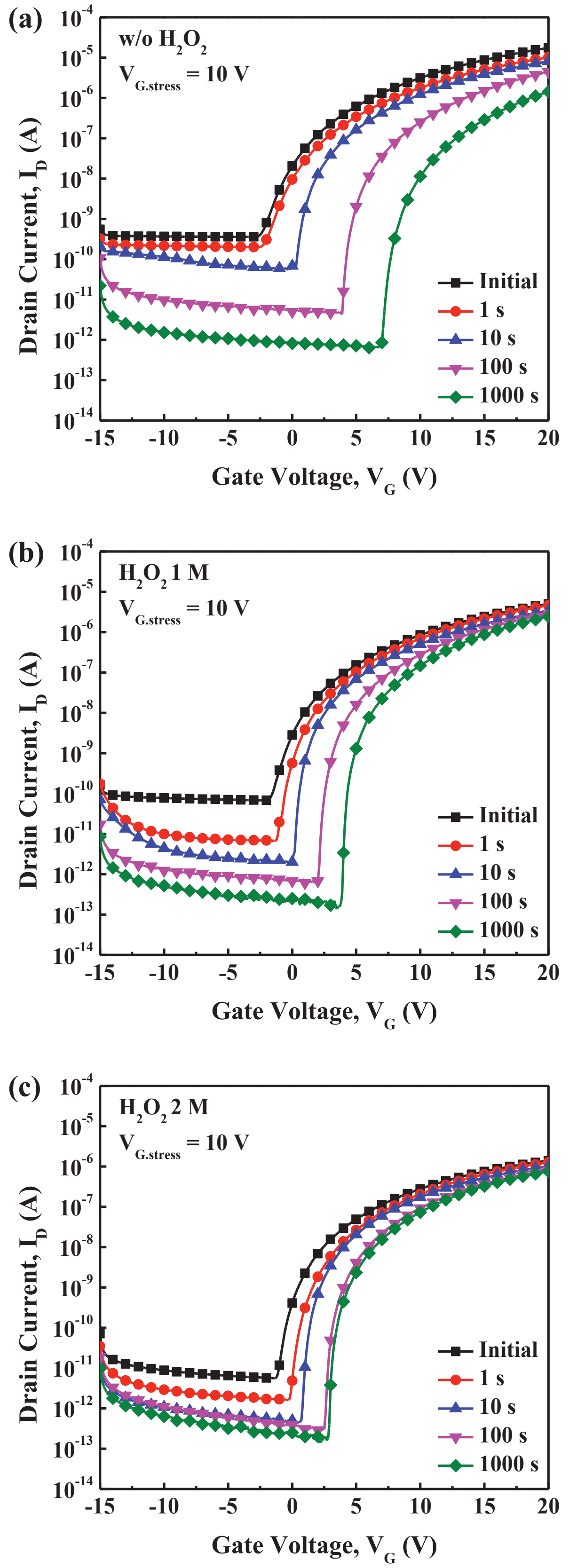

Fig. 3 Transfer curves of H_2O_2 incorporated ZIZO TFTs under positive gate bias stress

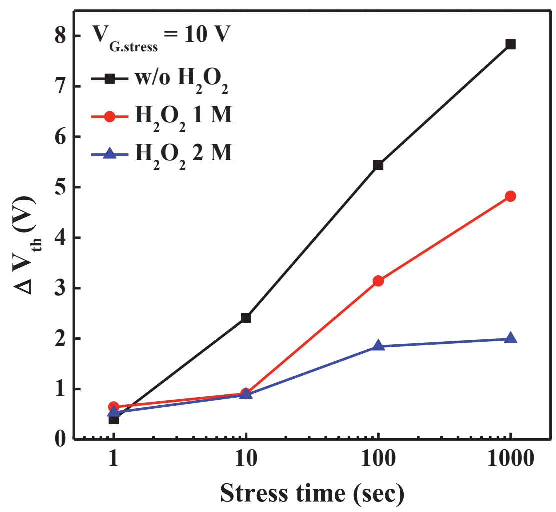

Fig. 4 ΔV_{th} comparison of H_2O_2 incorporated ZIZO TFTs under positive gate bias stress