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Photo-bias Instability of Solution Processed Zinc Tin Oxide Thin Film Transistors with Varying Zn:Sn Composition Ratio

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Zinc tin oxide thin film transistors (ZTO TFTs) have attracted a strong attention as a switching device because of their high mobility, good transparency, low temperature capability, and abundance in nature[1,2]. Recently, Solution processed metal oxide semiconductors have been intensively studied due to the merits of the low manufacturing cost and the application of large area[3]. Although the effect of Zn:Sn ratio on the device performance of the ZTO TFTs have been investigated in detail, few studies have been examined the relationship between material property and the photo-bias instability of ZTO TFTs. We fabricated the solution processed ZTO TFTs with different Zn:Sn composition ratio. The effect of the Zn:Sn composition ratio on the device performance and negative bias illumination stress (NBIS) instability was examined on the basis of the structural and chemical characterization of the ZTO films.

The precursor solutions of Zn and Sn was prepared by dissolving zinc acetate [$Zn(CH_3COO)_2$, Aldrich] and tin (II) chloride dihydrate [$SnCl_2 \cdot 2H_2O$, Aldrich], respectively, in 2-methoxy ethanol solvent of 6 mL with acetylacetone as a stabilizer, respectively. The total concentration of metal precursor in the solution was fixed at 0.15 M, and the molar ratio of Sn/(Zn+Sn) was 0.1 ~ 0.9. The metal precursor solution was stirred for 1h at 70 ^{o}C. Heavily doped p-type Si wafers with a 100-nm-thick thermally grown SiO_2 gate dielectric layer was used as a substrate. The spin coating was performed at 2000 rpm for 30 s. The resulting films were dried at 150 ^{o}C for 5 min to evaporate the solvent and annealed at 450 ^{o}C for 1 hr in air. Tin-doped indium oxide (ITO) as source and drain electrodes (S/D) was deposited by sputtering and patterned by a metal shadow mask. The width (W) and length (L) of the fabricated device was 1000 and 300 µm, respectively. Finally, to prevent the dynamic interaction between the channel layer and ambient oxygen/moisture, the fabricated device was encapsulated with polymethyl methacrylate (PMMA, MicroChem A4).

Figure 1 shows the dependence of transfer characteristics ($I_{DS} - V_{GS}$) of the ZTO TFTs with various at.% Sn. Although the result of X-ray diffraction (XRD) showed all the films were amorphous, the device performance was clearly influenced by the Zn:Sn ratio. The ZTO TFT with the highest at. % Sn showed poor $I_{on/off}$ of 3.6×10^2 and conducting behavior, which resulted from an increase of carrier concentration[4]. As the at. % Sn was decreased, the device performance was improved and the ZTO TFT at 44 at.% Sn exhibited a high saturation mobility (μ_{sat}), low subthreshold gate swing (SS), and $I_{on/off}$ of 4.4 $cm^2/(V\ s)$, 0.24 V/decade, and 5.7×10^7, respectively. However, the ZTO TFT for the Zn-rich composition showed extremely low μ_{sat} and high SS which can be attributed to low carrier concentration and high density states at the interface of channel/SiO_2.

The effects of Zn:Sn composition ratio on the NBIS instability of the resulting ZTO transistors were investigated. Figure 2 shows the evolution of the transfer characteristics as a function of the NBIS time for the ZTO TFTs with varying Zn:Sn ratio. The device with 66 at. % Sn suffered from a huge V_{th} shift of −16.8 V (Fig. 2a). However, the photo-bias stability was improved further by 44 and 28 at. % Sn : the devices showed a negative V_{th} displacement of only 3.9 and 1.9 V shift, respectively (Figs. 2b and c). The negative V_{th} shift in the NBIS condition can be attributed to photoionization of pre-existing neutral oxygen vacancy, trapping of photo-created hole carriers, and ambient interaction such as oxygen/moisture[5,6]. The latter mechanism can be excluded because the device was passivated by PMMA. In the oxygen vacancy model, the two electrons can be photo excited from neutral oxygen vacancies in the conduction band [$V_O \rightarrow V_O^{2+} + 2e^-$], and the migration of positively charged oxygen vacancy by negative bias applied to the gate electrode can induce free negative carriers in the channel, leading to the negative V_{th} shift. The XPS results of O 1s spectra for ZTO films with varying Zn:Sn composition ratio showed that the relative quantity of the oxygen vacancy at 531.2 eV were increased with increasing the at. % Sn (data not shown).

In summary, the effect of the Zn:Sn composition ratio on the device performance and photo bias instability of solution-processed ZTO TFTs was studied. The optimized composition ratio for the device performance was the range of 36-44 at. % Sn. However, the NBIS stability was improved with decrease of the at. % Sn. This improvement can be explained by the photo-created hole trapping model and V_o transition model, which are consistent with XPS result.

Reference

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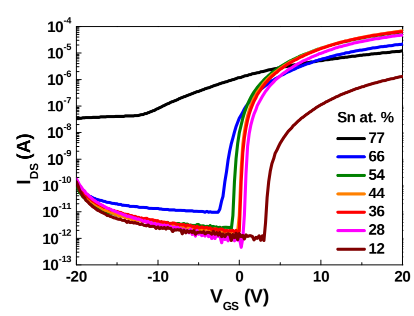

Fig. 1. Transfer characteristics of ZTO TFTs with varying at.% Sn.

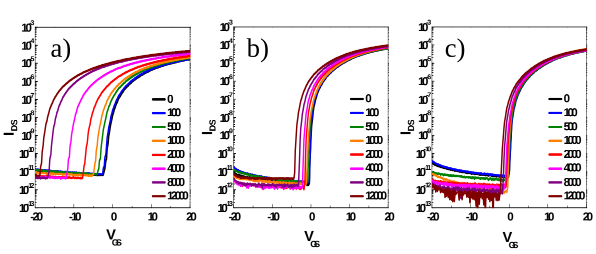

Fig. 2. Variation in V_{th} value as a function of the applied NBIS time for the ZTO TFTs with varying Sn content: a) 66, b) 44, and c) 28 at. % Sn.