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Effect of active layer thickness on device performance of a-LZTO thin-film transistors

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ABSTRACT

The dependence of the electrical properties of amorphous lanthanum–zinc–tin–oxides (a-LZTOs)-based top-gate thin-film transistors (TFTs) on active layer thicknesses (d_T) is investigated. It is found that the on-to-off current ratio ($I_{on/off}$) of TFT improved with the thickness of LZTO active layer decreased from 84 nm to 32 nm, whereas the saturation mobility and the subthreshold swing of device degraded. The improvement in $I_{on/off}$ is attributed to the decrease in off-current of TFT due to an increase in resistance of the very thin LZTO film. Moreover, the deterioration in properties of device with the thin active layer is associated with the trap states incorporated in TFT and interface scattering effect.

1. Introduction

There is substantial interest in the use of amorphous oxide semiconductors (AOSs) as the active layer for thin-film transistors (TFTs) since high-performance amorphous In–Ga–Zn–O (a-IGZO) TFTs were reported [1]. Studies on AOSs based TFTs have mainly focused on two aspects. Developing less indium amount even indium-free without significant reduction of electrical properties has been a long term goal, especially considering the high cost of indium due to its scarcity. Moreover, the TFTs fabrication technology has been continuously developed for simple processing steps and reducing cost in the process of mass production.

Indium-free Zn–Sn–O (ZTO) thin film as a promising AOS material has received much attention on the strengths of its high visible transmittance, stable amorphous structure, good n-type electrical conductivity, low cost, and its tendency to possess an exceedingly smooth surface in thin films

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[2,3]. In addition, the solution process offers a simple and low cost thin film deposition process as an alternative to the vacuum deposition technique. Recently, although several groups have attempted to fabricate ZTO thin films by solution process and apply to TFTs, most of ZTO thin films were formed by spin coating or inkjet printing [4–8]. The dip coating method was seldom reported in the fabrication of oxide TFTs. In our previous work [9], we combined dip-coated lanthanum–zinc–tin–oxides (LZTOs) active layer and dip-coated poly (methyl methacrylate) (PMMA) gate insulator, to study the effect of La content in ZTO film on the TFT's performance. And it was found that La acted as a carrier suppressor, which lead to realize the controllability of the carrier concentration in ZTO active layers. The optimized TFT performance was obtained at La content of 9%.

In generally, it is the tendency to continuously decrease the thickness of active layers in order to improving throughput for active material deposition and satisfying demand for the miniaturized development of electronic devices [10]. Interestingly, it is found that the saturated mobility of TFT markedly degraded for thin LZTO active layer (e.g. 32 nm) in our recent experiment. This phenomenon reveals that the active layer thickness may be one of the key factors that substantially influence the electrical properties of solution-derived oxide TFTs. However, the effect of active layer thickness has not been investigated particularly and the mechanism is still unclear. In this work, we investigated the dependence of the electrical properties of a-LZTO TFTs on active layer thicknesses, which cannot only help in selecting the optimum thickness of LZTO active layer in realistic applications but also help in further understanding the mechanism behind.

2. Experimental details

A top-gate and top-contact structure was employed in this study. The precursor solution of LZTO was prepared by dissolving analytical reagent zinc acetate [$Zn(CH_3COO)_2$], tin chlorides [$SnCl_2$], and lanthanum nitrate [$La(NO_3)_3$] in ethylene glycol solvent. Ethanolamine was added as a stabilizer to improve the precursor solubility. 9 mol% La-doped ZTO (Zn:Sn = 1:2) thin films were deposited on glass using a dip coating method. Then, the dip-coated LZTO film was preheated at 200 °C for 30 min and annealed at 500 °C for 2 h in air ambient. The thickness of thin films was controlled by the number of times of dip coating performed with thicknesses ranging from 32 nm to 84 nm. The 280-nm-thick PMMA gate insulator was also prepared by dip coating method. The 90-nm-thick aluminum source/drain/gate electrodes were formed through shadow mask by thermal evaporating. The channel length and width were 100 μm and 500 μm, respectively.

The thermal decomposition behavior of the sol–gel precursor solution was monitored under ambient atmosphere using a thermogravimetric analyzer (Q500). X-ray diffractometer (XRD) measurements were carried out with a diffractometer (D8 Advance) using Cu Kα radiation. The index of refraction of sample was measured using an n&k Analyzer 1280. The thicknesses of films and electrodes were evaluated by a stylus profilometer (Kosaka Laboratory ET3000). The performances of TFTs were analyzed using Keithley 4200 semiconductor parameter analyzer.

3. Results and discussion

Thermogravimetric analysis (TGA) was performed to elucidate the formation mechanism of LZTO thin films. The resultant TGA curve of the LZTO sol–gel precursor solution is shown in Fig. 1. The abrupt weight loss between 100 °C and 200 °C is attributed to the thermal decomposition of organic anion groups and evaporation of the solvent. The slight weight loss observed above 200 °C is associated with dehydroxylation [11,12]. The decomposition was completed at around 400 °C, suggesting a 500 °C annealing temperature works well for the formation of LZTO thin films.

Fig. 2 shows XRD patterns of the LZTO thin films with various thicknesses (32 nm, 57 nm and 84 nm). It is indicated that the films were amorphous phase even when annealed at 500 °C for 2 h. Therefore, a-LZTO films as active layers in TFTs were considered to be promising since an amorphous phase is superior to a crystalline phase for device performance uniformity. Fig. 3 shows the spectra of refractive index (n) of a-LZTO thin films for the different thicknesses. With film thickness varies from 32 nm, 57 nm and 84 nm, the n value (at 550 nm) of LZTO films changes as 1.76, 1.87 and