Microelectronic Engineering 109 (2013) 189–192

Contents lists available at SciVerse ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Effect of aluminum addition to solution-derived amorphous indium zinc oxide thin film for an oxide thin film transistors

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ARTICLE INFO

Article history:
Available online 29 March 2013

Keywords:
Solution-derived thin film transistors
Al-IZO
Oxide TFT
Amorphous oxide TFT

ABSTRACT

Aluminum-doped indium zinc oxide (IZO) thin film transistors (TFTs) were fabricated to examine the effect of aluminum incorporation in the solution-derived channel layer of TFTs. The IZO channel layer containing aluminum was amorphous. The addition of aluminum suppressed the carrier concentration of the channel layer and affected the electrical characteristics of the TFTs. The bottom-gate TFTs were manufactured on highly doped n-type silicon wafers coated with a SiO_2 layer as a gate insulator. An aluminum-doped IZO solution was spin coated on the SiO_2 layer and annealed in air. The molar ratio of aluminum-versus-indium-versus zinc was changed to determine the optimized molar ratio of a channel layer of TFTs depending on the annealing temperature and layer thickness. The optimized aluminum-doped indium zinc oxide TFTs exhibited a high on/off current ratio of $\sim 3.0 \times 10^6$, a threshold voltage of ~2 V and a low subthreshold swing of 0.76 V/dec, respectively.

1. Introduction

Oxide-based thin films for various applications, such as displays, solar cells and sensors, have been much examined in recent years [1–3]. Oxide-based thin films are prepared using a range of methods, such as chemical vapor deposition, rf sputtering [4–6], pulsed laser deposition [7] and solution-derived process. Solution-derived oxide-based thin films have attracted considerable attention for their advantages of a simple process, low cost and convenience for applications to large area display devices compared to oxide thin films prepared by vacuum processes [8,9]. But the solution-derived oxide-based thin films still need many researches to adjust for thin film transistors (TFTs). Therefore, chemical modulation is essential for controlling the electrical properties of oxide thin films. In previous studies, InZnO [10,11], ZnSnO [12], InGaZnO [13,14] and Mg-InO [15] have been evaluated for the chemical compound modulation of oxide thin films. Among the numerous materials for chemical composition, aluminum has potential as a carrier suppressor because of its low standard electrode potential (SEP), which is a parameter for oxidation, and abundance in the Earth, which will reduce the cost of the resulting TFTs [16].

In this study, aluminum added IZO solutions were prepared with various Al ratios, and TFTs were manufactured with an Al-IZO channel layer produced by spin-coating. This study examined the effects of the Al ratio on the surface morphology of the films and the electrical performance of the resulting Al-IZO TFTs.

2. Experimental details

The metal precursor solution for fabricating Al-IZO thin films was prepared by dissolving 0.2 M of zinc acetate dehydrate ($Zn(OAc)_2 2H_2O$), indium nitrate hydrate ($In(NO_3)_3 \times H_2O$), and aluminum chloride ($AlCl_3$) in 2-methoxyethanol as a solvent. The aluminum-versus-indium-versus zinc molar ratio was varied to determine the optimal molar ratio of the channel layer in TFTs. The Zn:In molar ratio was fixed to 2:3, and the Al ratio was varied from 0.1 to 0.6. In subsequent experiments, the Zn:In molar ratio was fixed to 1:1, and Al was varied from 0.1 to 0.3. To stabilize the solution, the precursor solution was mixed with a small amount of ethanolamine (C_2H_7NO) and stirred at 65 °C for 1 h to make a transparent solution. The solution was then filtered through a 0.22 μm syringe filter and deposited on the substrate by spin-coating method at 4500 rpm for 30 s. The Al-IZO thin films underwent hotplate annealing at 450 °C for 1 h in ambient air. Fig. 1 presents the TFT structure, including the channel width (W) and length (L). Heavily doped n-type silicon wafers with an inverted-gate structure were used for the fabrication of Al-IZO TFTs. A 200 nm thick SiO_2 layer was grown thermally on top of the silicon wafer as a gate insulator. After annealing the Al-IZO thin films, a 120 nm thick Al layer as the source and drain electrodes was deposited on the top of the Al-IZO layer by electron-beam evaporation. X-ray diffraction (XRD) was used to examine the microstructural properties of the films. The surface morphology of the Al-IZO

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http://dx.doi.org/10.1016/j.mee.2013.03.121

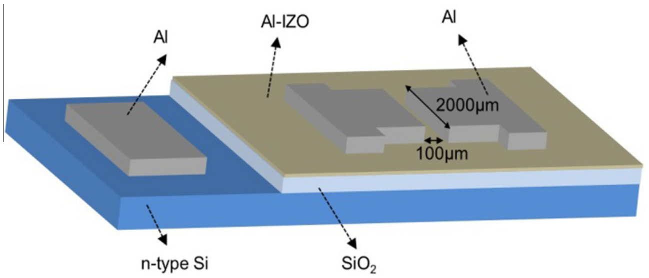

Fig. 1. Device structures of the fabricated aluminum added indium zinc oxide TFTs.

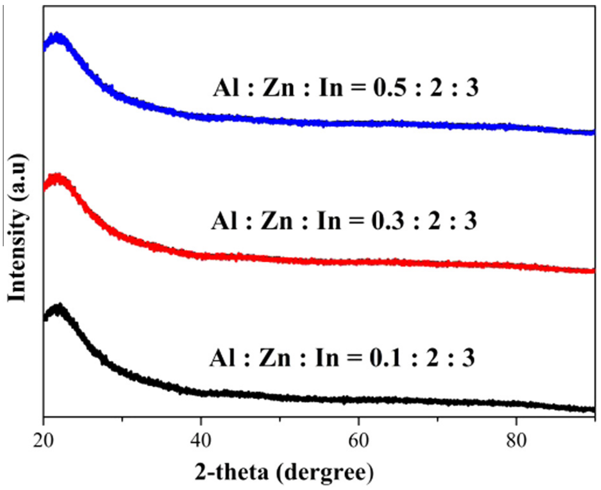

Fig. 2. XRD spectra of the spin coated Al-IZO films with different Al contents.

films was examined by atomic force microscopy (AFM). The composition and chemical states of the deposited films were characterized by X-ray photoelectron spectroscopy (XPS). The band gap of thin films was estimated by ultraviolet/visible (UV/vis) spectrophotometry.

3. Results and discussion

Fig. 2 shows XRD patterns of the Al-IZO films with different Al contents. All the deposited films on glass were heated gradually to 450 °C. None of the XRD patterns showed significant diffraction peaks, indicating most of the solution-derived Al-IZO films to be amorphous. Tominga et al. [17] reported the effects of Al impurities in the structural properties of amorphous IZO films. According to their report, the addition of Al impurities to amorphous IZO film extends the Zn content where the amorphous structure appears. Fig. 3 presents AFM images of Al-IZO films with a range of Al molar ratios along with the average surface roughness of the samples. The root-mean-square roughness (rms) of the thin films was reduced slightly by increasing the Al contents. The surface morphology of the Al-IZO films tended to become smooth and showed an amorphous state as the amount of Al was increased. XPS was performed to examine the chemical states of the Al-IZO thin films. Fig. 4a and Fig. 4b shows the XP spectra of the Al 2p and O 1s states of the thin films. In Fig. 4a, the Al 2p core-level peak was observed at 74.6 eV [18] and the Al 2p core-level peak became more distinct with increasing Al content. In Fig. 4b, the O 1s peak, which is related to O^{2-} ions combining with In and Zn, was measured at 530.7 ev [19]. The O 1s peak showed a relative decrease with increasing Al content in the thin film. Therefore, increasing the Al content might affect the indium zinc oxide structure by producing an amorphous state, and Al incorporation is an impurity in the indium zinc oxide structure, hindering the combination of the IZO structure.

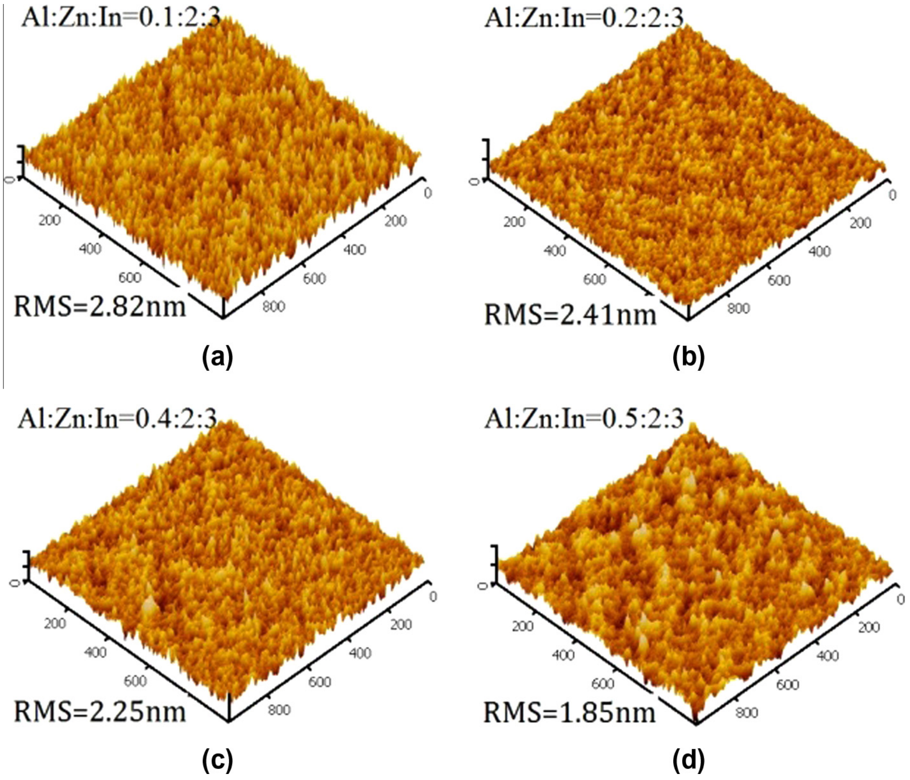

Fig. 3. AFM images of the Al-IZO thin films with different Al ratios.