Eco-Friendly, Low-temperature Solution-processed InO/AlO Thin-film Transistor with Li-incorporation

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***Abstract*—In this work, we investigate an eco-friendly route of fabricating solution-processed thin-film transistors (TFTs). With Li incorporation in indium oxide (InO) semiconductor layer, the annealing temperature could be lowered to 200 °C. With the combination of solution processed high-*k* aluminum oxide (AlO) dielectric layer, the TFT field effect mobility achieved an average value of 20.5 cm^2·V^{-1}·s^{-1} among 30 samples, which is a promising result for future applications.**

Keywords-component; TFT; solution process; InO; Li incorporation

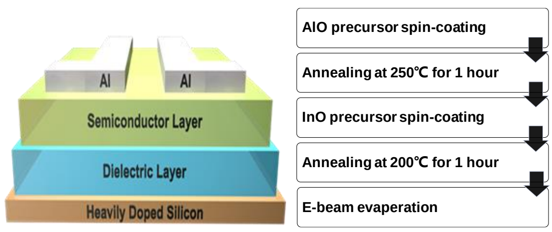
I. INTRODUCTION

Recently, the outstanding charge transport properties and excellent optical transparency of metal oxide thin-film transistors (MOTFTs) attract much investigation for the applications in state-of-the-art flat panel display technologies and next-generation electronics [1]. To date, among variety of metal oxides (MOs), InO based semiconductors are important candidates for TFTs fabrication [2]. In the past few years, the solution method has drawn attention for the preparation of MOTFTs due to its relative low-cost, simple process and potential in depositing high quality films [3]. Nevertheless, high annealing temperature (>400 °C) processing inhibits the development of solution processed MOTFTs due to unfeasibility in the implementation of high-performance oxide materials on various soft substrates [4, 5]. Moreover, toxic solvents such as 2-methoxyethanol (2-Me) et al. are still widely used in the preparation of precursor solutions[6]. Therefore, a low-temperature (<300 °C) route for high performance solution processed MOTFTs with eco-friendly solvent are being researched.

In this work, we report on high mobility TFTs with solution processed Li incorporated InO semiconductor and AlO dielectric layer. The whole process was operated at a low temperature below 250 °C and the precursor solvents were di-ionized (DI) water-based without hazardous additives. Remarkably, the TFTs with 10 at.% Li incorporation reached an average mobility of 20.5 cm^2·V^{-1}·s^{-1}, which is a breakthrough in comparison to recent reports [5, 7, 8].

II. EXPERIMENTAL

As Fig. 1 depicts, the InO/AlO thin-film transistors were fabricated with a bottom-gate top contact configuration. For the InO/AlO stack layer, the precursor was prepared through dissolving aluminum nitrate nonahydrate ($Al(NO_3)_3·9H_2O$, Aladdin) and indium nitrate hydrate ($In(NO_3)_3·xH_2O$, Aladdin) in DI water respectively. The two solutions were given an ultrasonicate treatment for 10 min and filtered through 0.45 µm poly(ether sulfone) (PES) syringe before spin coating and annealing at 200/250°C in ambient condition to fabricate InO/AlO layers respectively. During the processes, different amounts of lithium acetate ($LiOOCCH_3$, Aladdin) were added to InO precursor solution in order to fabricate InO layer with different Li incorporation (0 at.%, 5 at.%, 10 at.%, 15 at.%). Finally, the 100 nm-thick Al electrodes with W/L ratio of 15 were deposited layer via e-beam evaporation.

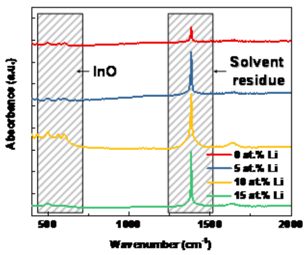


(a) (b)
Figure 1. (a) Schematic diagram and (b) fabrication flow of the low-temperature, eco-friendly InO/AlO TFTs.

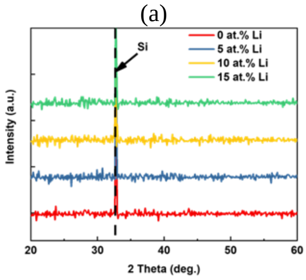
III. RESULTS AND DISCUSSION

Fig. 2(a) displays the Fourier Transform Infrared (FTIR) spectroscopy results of solution processed InO films with different Li concentrations of 0, 5, 10 and 15 at.%. The shallow peak at ~1400 cm^{-1} can be attributed to the deformation vibrations of solvent residue such as NO^{3-} [2]. The peaks in the range of 400 to 600 cm^{-1} could result from the phonon vibrations of In-O bonds [9]. As shown in the figure, the intensity of the InO peaks increased with the concentration of Li ion and reached a maximum value for 10 at.% Li doped samples. This phenomenon could be attributed to Li assisting the formation of In-O network [10]. Nevertheless, excessive doping of Li would lead to a negative effect, mainly due to the destruction of the InO microstructure. Thus, a reduction of intensity occurred when the Li concentration went up to 15 at.%. The above analysis is consistent with previous studies [11, 12]. To investigate the crystallization of the solution processed InO layer, XRD measurements were carried out, and the results are shown in Fig.2(b). The peaks at 33° are mainly due to the Si substrate, while the InO films exhibit an amorphous structure [13].

The transfer characteristics of the InO/AlO with 10 at.% Li incorporation are shown in Fig. 3 which depicts a mobility of average 20.5 $cm^2 \cdot V^{-1} \cdot s^{-1}$ among 30 samples. Compared to recent reports of low temperature (≤ 260 °C) solution processed InO/AlO TFTs, the mobility of TFTs with Li incorporation in this work made a distinct improvement of more than 50% [5, 7, 8]. The significant enhancement of mobility is mainly due to the n-type doping effect induced by Li incorporation [14]. The counter clockwise hysteresis of the transfer current is thought to result from mobile impurity ions in the gate oxide near the channel region [15]. Moreover, the TFT



(a)



(b)

Figure 2. (a) FTIR and (b) XRD spectra of InO films annealed at 200 °C with different concentration of Li incorporation.

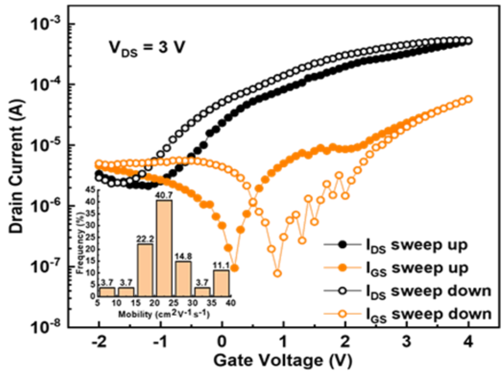


Figure 3. Transfer (Drain Current vs. Gate Voltage) characteristics of the InO/AlO TFTs annealed at 200℃/250℃.

devices exhibited an average threshold voltage of 0.1 V, subthreshold swing of 0.67 V/dec and on-off ratio of 1000.

IV. CONCLUSION

In conclusion, we investigated fully solution-processed Li incorporated InO/AlO thin-film transistors through an eco-friendly solvent route. All processing was carried out below 250 °C. The physical properties of the aqueous solution-processed InO with 0 to 15 at.% Li were investigated by FTIR and XRD. The InO TFTs with 10 at.% Li ion doping reached a high average mobility of 20.5 $cm^2 \cdot V^{-1} \cdot s^{-1}$ among 30 samples showing a factor of X increase on the current state of the art.

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