Design of Optimized Solution Processed Oxide TFT Composition by Addition of Aluminum to Indium Tin Oxide

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Abstract

Aluminum was added to solution-processed conductive indium tin oxide thin film to be optimized as a channel layer for the thin film transistor. The systematic variation of TFT characteristics was observed clearly, displaying the transformation to the semiconductor with increasing the Al content. AITO TFTs annealed at 400°C and 500°C were optimized at the final composition of x=0.2 and x=0.4 of $(Al_2O_3)_x(In_2O_3)_{0.9-x}(SnO_2)_{0.1}$. *Each channel layer operated in enhanced mode and exhibits mobility of 3.33 and 4.48* $cm^2 \cdot V^{-1} \cdot s^{-1}$ *which is applicable to the backplane of flat panel displays.*

1. Introduction

Amorphous oxides with heavy-metal cations, such as indium zinc oxide (IZO)[2], zinc tin oxide (ZTO)[3] and indium gallium zinc oxide (IGZO)[1], have been researched for a channel layer of oxide TFT. To improve the TFT performance, the defect control by varying their compositions have been considered.[1,4] The defect chemistry of these materials and their derivative compositions play major roles in affecting their optical and electrical properties for the use of transparent electronics. Recently, it was reported that aluminum could be an additive in semiconducting oxides because it has not only higher bonding energy with oxygen than Ga but also is plentiful on earth, resulting in low cost. Al_2O_3 is well-known as a good amorphous state stabilizer. We previously reported that indium tin oxide (ITO) thin films fabricated by sol-gel method are transformed from the conductor to the semiconductor by simply adding aluminum into the composition to enlarge the band gap and to become an amorphous phase.[5] Consequently, more studies about the optimized composition of AITO channel layer were needed.

In this letter, it is observed that the optimized composition of solution-processed aluminum indium tin oxide (AITO) thin film channel layer in TFT shows the good performance of high mobility, high on-to-off current ratio, and low sub-threshold swing, which are applicable to the backplane of flat panel displays.

2. Experimental

ITO solution were prepared by dissolving precursors with a molar ratio 90% of indium acetate and 10% of tin chloride in 2-methoxyethanol. For the addition of aluminum to ITO solutions, we replaced a molar ratio of 20~40% of aluminum acetylacetonate with indium precursor while constant 10% of tin precursor maintains. In order to form stable solutions, ethylenediamine added as a chelating agent. The solutions were annealed at 400°C and 500°C in air for 1hours after spin-coating on SiO_2/p^+-Si substrate at a speed of 5000 rpm for 30s. To fabricate and characterize the AITO TFTs, the fabricated thin film as an active channel layer, 100 nm thick aluminum electrodes for source - drain contacts were deposited on oxide film on SiO_2/p^+-Si structure by e-beam evaporation. To form an inverted gated device structure (Al/Oxide thin film/SiO_2/p^+-Si) The TFT characteristics of the devices were analyzed using a HP 4145B semiconductor parameter analyzer in the dark room at ambient condition.

3. Results and discussion

Fig. 1 shows the transfer curves of the TFTs with various composition oxide thin film channel layer. With the addition of Al into ITO composition, the current level is lowered showing the off-state for the device to become a transistor. As the Al content in the channel layer increases further, the negative threshold voltage shifts toward zero and the current level difference between on and off states becomes greater, clearly displaying semiconducting property. The TFT for x=0.2 of composition $(Al_2O_3)_X(In_2O_3)_{0.9-X}(SnO_2)_{0.1}$ at channel shows the best overall device performance. For this sample, the carrier mobility is around 3.33 $cm^2 \cdot V^{-1} \cdot s^{-1}$, whereas the on-to-off current ratio is close to 7×10^7. The off-current remains lower than 10^{-11} A and the sub-threshold swing is 0.37 V/decade. In Fig. 2, the optimized AITO TFT for x=0.4 $(Al_2O_3)_X(In_2O_3)_{0.9-X}(SnO_2)_{0.1}$ shows the carrier mobility is around 4.48 $cm^2 \cdot V^{-1} \cdot s^{-1}$, whereas the on-to-off current ratio is close to 5×10^8. The off-current remains lower than 10^{-12} A and the sub-threshold swing is 0.61 V/decade. These TFT characteristics of two samples are represented at Table 1. As the Al content grows more, on-state current is reduced and V_{ON} shifts positively. It means that we have to apply higher voltages to move the carrier. This systematic variation in the transfer curve with addition of Al is well explained by the relationship the band-gap and electronic structure.[5] Al is light-metal cation with small ns orbital so that addition of Al suppresses the overlapping between adjacent metal cation and produces less oxygen vacancy resulting in low carrier concentration due to its higher chemical bonding energy with oxygen. Besides, It needs higher energy for moving carriers over E_g due to the formation of AlO_X in AITO channel. Oxygen vacancy is well-known donors in most n-type TCOs such as ITO and it makes Fermi levels near or within conduction bands and ITO usually has more oxygen vacancy at higher annealing temperature, resulting in high carrier concentration. In this study, the sample annealed at 500°C has more oxygen vacancy so that we needs higher compositions of Al addition for compensating oxygen vacancies to get semiconducting property than that of annealed at 400°C.

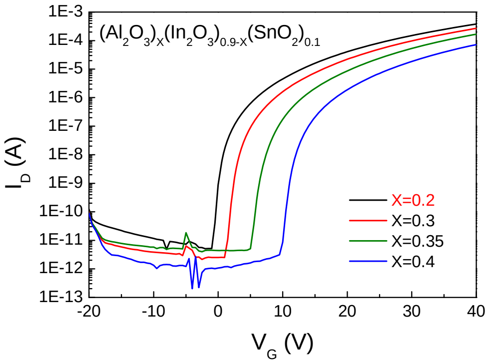

Fig. 1. AITO TFTs with various Al content annealed at 400°C.

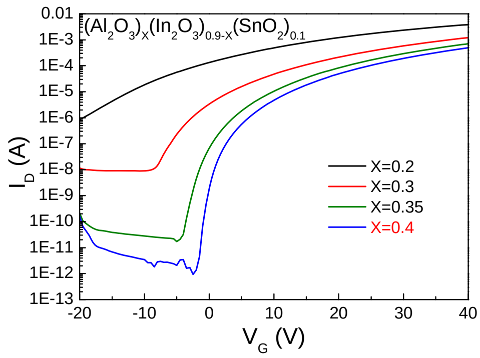

Fig. 2. AITO TFTs with various Al content annealed at 500°C.

Table 1. TFT characteristics

Sample	μ $[cm^2 \cdot V^{-1} \cdot s^{-1}]$	$I_{on/off}$	S.S. [V/dec.]
400°C, x=0.2	3.33	7×10^7	0.37
500°C, x=0.4	4.48	5×10^8	0.61

4. Summary

In summary, we optimized aluminum indium tin oxide channel layer for oxide TFT by changing the composition simply with Al addition to solution-processed conductive indium tin oxide thin film for application to the backplane of flat panel displays. With increasing Al contents, the electrical behavior resulted in lower off-current and Von shifts positively. Al addition could contribute to the nonguaranteed electronic path due to the insufficient overlapping because of small *ns* orbital of Al and to the lowered carrier concentration due to larger band-gap by formed aluminum oxide in ITO thin film. Each optimized composition of AITO channel layer which were annealed at 400˚C and 500˚C is x=0.2 and x=0.4 at $(Al_2O_3)_X(In_2O_3)_{0.9-X}(SnO_2)_{0.1}$. They showed high carrier mobilities of 3.33 and 4.48 $cm^2 \cdot V^{-1} \cdot s^{-1}$, high on-to-off current ratios of 10^7 and 10^8, low sub-threshold swings less than 1 V/dec. We could approach from this study how aluminum affects to the electronic structure of Al-added oxide thin film with annealed at two different temperatures and obtain the AITO channel property which is applicable to transparent electronics at each annealing temperature.

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